DFMA in Product Development

A case study for K. Hartwall Oy Ab

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Abstract:

This thesis is to study the possibilities to implement Design for Manufacturing and Assembly methods into K. Hartwall's product development. This study has been executed as a case study and one of K. Hartwall's products has been analyzed part by part according to Boothroyd's methods of DFMA. The goal with these methods is to reduce the number of components in the final assembly stage to achieve cost savings. DFMA methods does not take to account the products full lifecycle but only the early stages of development. First the product was analyzed and then it was modified and redesigned using SolidWorks and then the savings were calculated using Boothroyd's methods. Lastly the new and old design were compared to see the total cost saving.

After the modification to the product had been done, the total amount of components was reduced from 116 to 69 components. Most of the removed parts were bolts and nuts that according to Boothroyd's methods are the costliest in a final assembly. The list of separate components was also reduced from 37 different components to only 31 different components. After calculating the time savings of all the modifications, the new design ended up having a 38% shorter production time, theoretically speaking and a theoretical cost reduction of 12.2%. With these results the study can be considered a success and to conclude the results shows that K. Hartwall should continue investigating the value of implementing DFMA methods to their product development stage.

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EXTENDED ABSTRACT IN SWEDISH

Denna avhandling är utförd som ett beställningsarbete för K. Hartwall Oy Ab. K. Hartwall är ett nästan 90 år gammalt familjeföretag baserat i Söderkulla, Sibbo och de säljer, producerar och utvecklar olika typer av produkter för att effektivera logistik. Till deras produkter hör bland annat de mjölkkärror man kan se i matbutiken eller de rull-burar som bland annat finska posten använder.

Målet med denna avhandling är att utforska Geoffrey Boothroyds metoder om 'Design For Manufacturing and Assembly', eller förkortat till DFMA, samt K. Hartwalls möjligheter att implementera dessa metoder i sin produktutveckling. Denna avhandling kommer att göras i form av en fallstudie. Fallstudier är ett billigt och tidseffektivt sätt att se ifall det är värt att fortsätta med mer omfattande forskning i ett ämne utan att slösa både tid och pengar. DFMA-metoden strävar efter att effektivera produktutvecklingen i företag och att i ett tidigt skede få en bild över hur en produkt kommer att produceras. Genom att designa en produkt och beakta produktionen och slutmonteringen redan i det tidiga design skedet, kan man reducera kostnaden för produkten. Genom att ha en produktdesigner som samarbetar och för öppen dialog med fabrikören som tillverkar produkten, kan potentiella dyra, svåra eller komplicerade aspekter av en design elimineras i ett tidigt skede.

I denna avhandling kommer en existerande produkt från K. Hartwalls sortiment att analyseras del för del baserat på Boothroyds teorier. Efter att alla komponenter är analyserade kommer produkten att designas om enligt en mer kostnadseffektiv design. Enligt Boothroyds teorier leder färre enskilda komponenter i slutmonteringsskedet till kostnadsbesparingar. Boothroyd utvecklade dessa metoder då hans undersökningar visade att de gamla metoderna inte alls var så kostnadseffektiva som man tidigare trodde. Enligt de gamla metoderna trodde man att ifall man gör komponenterna så billiga och enkel som möjligt kommer produkten att bli mycket billigare, även fast det blir mycket fler enskilda komponenter. Boothroyds teorier säger raka motsatsen, att dyrare men färre komponenter leder till en billigare produkt.

Produkten som kommer att analyseras i denna avhandling är en så kallad rull-container som K. Hartwall tillverkar för en global nätbutiks logistikcentraler. Rull-containern har fyra hjul, en baskonstruktion, tre väggar i metallnät och en öppen sida. Två av hjulen är svänghjul och två är fasta. Rull-containern har även en bromsmekanism som kan aktiveras genom att dra åt en spake. Alla väggar är enskilda komponenter och är fastsatta i varandra med flera bultar och muttrar. Golvet i basen är en separat skiva av plast och under den befinner sig bromsmekanismen som består av en axel, några fjädrar och flertal bultar och muttrar av olika slag.

Fallstudien inleddes med att gå igenom produktens alla komponenter del för del och analysera vilka förbättringsmöjligheter det fanns baserat på Boothroyds metoder. I det här skedet är målet att se hur mycket som är möjligt att förbättra. Boothroyds huvudsakliga regler för analysering av en produkt är följande:

- Om komponenten inte måste röra på sig i förhållande till resten av produkten kan den elimineras eller kombineras med en annan komponent.
- Om komponenten inte behöver vara av annat material eller av annan orsak måste isoleras, kan delen elimineras eller kombineras med en annan komponent.
- Om komponenten underlättar slutmonteringen kan den få hållas separat, annars skall den elimineras eller kombineras med en annan komponent.

Genom att följa de ovannämnda reglerna analyseras produkten för att se vilka delar som behövs och vilka som kan tas bort eller designas om så att den delens funktion kan inkluderas i en annan del. Utöver dessa huvudregler finns det även rekommendationer på hur det lönar sig att designa en komponent och vad det lönar sig att tänka på för att underlätta slutmonteringsprocessen så mycket som bara möjligt. Till dessa rekommendationer hör saker som att hellre använda snäpplås istället för bult och mutter då det är en snabbare lösning samt att göra komponenter så symmetriska som möjligt för att underlätta placeringen av komponenten. Det finns även rekommendationer att väldigt små eller vassa komponenter som är svåra eller farliga att hantera ska försöka undvikas så långt det går.

Efter att analyseringsprocessen slutfördes var det dags att designa om produkten. Designarbetet är gjort i SolidWorks, då den ursprungliga produkten var designad i samma programvara. Efter att produktens designarbete var klart hade antalet komponenter reducerats från 116 komponenter till endast 69 komponenter, varav största delen var bultar och muttrar. Totalt fanns det alltså 116 komponenter, men eftersom det fanns många komponenter i produkten som var samma, var den totala mängden olika komponenter 37. Av dessa 37 komponenter kunde sex komponenter elimineras helt och hållet, vilket gjorde att den slutliga mängden komponenter kunde reduceras till 31.

Då arbetet med att designa om produkten var slutfört gjordes beräkningar på både den gamla och den nya designen. Baserat på Boothroyds teorier gjordes först en Design For Assembly-analys (DFA) för att räkna ut produktens teoretiska monteringstid. Denna kalkyl görs för att kunna jämföra produktionstiden för den gamla och med den nya produkten, vilket gör att man kan se skillnaden i produktionstid för att se ifall man lyckats reducera produktionstiden. I denna fallstudie reducerades slutmonteringstiden från 35 min till endast 18 min, vilket betyder en 51,5% reducering. Då man tar i beaktande att slutmonteringstiden är ungefär 75% av hela produktionstiden kan man kalkylera den totala tidsreduceringen till 38% för hela produktionstiden.

Följande del i denna fallstudie är Design For Manufacturing (DFM), som används för att undersöka ifall den nya designens komponenter är dyrare eller billigare att producera. Den här delen sköttes av K. Hartwalls egna experter som på daglig basis utför kalkyler av detta slag för att få ett så pålitligt resultat som möjligt. Resultatet från deras analys gav att den nya designen kostade nästan lika mycket att producera som den ursprungliga designen. Den nya designen skulle vara ca 1% billigare att producera.

Efter alla de ovannämnda kalkylerna är det möjligt att räkna ut hela studiens resultat. Genom att konvertera tidsreduceringen på 38% till pengar och tar DFM-analysen i beaktande, är det möjligt att dra slutsatsen att de totala besparingarna gjorda i denna studie är en teoretisk reducering på 12,2% av produktens hela produktionskostnad. Det betyder att varje enskild produkt som tillverkas är 12,2% billigare. Genom att få ner produktionspriset på en produkt kan man antingen sänka försäljningspriset för att vara mer konkurrenskraftig på marknaden men å andra sidan är det även möjligt att öka vinsten på produkten ifall priset inte sänks.

Stor del av de ändringar som gjordes i modellen var reduceringar av bultar och muttrar som är tidskrävande processer i slut monteringen. Även elimineringen av olika material, små delar och andra svårhanterade delar bidrog till resultatet. Om den nya designen faktiskt fungerar i praktiken bör ännu testas då denna undersökning var enbart teoretisk.

Det är möjligt att dra slutsatsen att denna fallstudie lyckades eftersom målet med studien var att hitta ett sätt att reducera produktens produktionskostnader, och det målet uppfylldes. Baserat på detta resultat går det även att dra slutsatsen att det definitivt lönar sig för K. Hartwall att vidare undersöka hur de kan implementera DFMA-metoder i sin produktutveckling.

FOREWORD

I wish to express my sincere appreciations to K. Hartwall for giving me the opportunity to research a fantastic and interesting topic in a “real world environment”. I want to thank Jussi Raninen and Jari Lainpelto from K. Hartwall for the practical guides for executing this study. I also want to thank Jack Grönholm who together with Raninen trusted me with the task and huge tanks to everyone at K. Hartwall that have helped me during this time.

I want to give my hugest appreciation for all the valuable guides Mathew Vihtonen have given me during the research. He has been an excellent supervisor to guide me through this study with great advice and technical guidance.

I want to thank all teachers and other staff at Arcada that have guided and supported me during my four years to become a matured person with an Engineering degree.

Finally, I want to thank all my friends and family who have supported me during this time and have motivated me even through the most challenging times. Their support has never been as valuable as during the time of this thesis work.

ABBREVIATIONS

DFMA	=	**Design for Manufacturing and Assembly**
FMCG	=	**Fast-moving consumer goods**
DMAIC	=	**Define, Measure, Analyze, Improve, Control**
DFA	=	**Design for Assembly**
DFM	=	**Design for Manufacturing**
CAD	=	**Computer Aided Design**
CAM	=	**Computer Aided Manufacturing**
$P(\%)$	=	**Percentual difference of new and old time**
$t_{new}(s)$	=	**Time off assembly in new model**
$t_{old}(s)$	=	**Time of assembly in old model**

1 INTRODUCTION

1.1 Background

To stay competitive as a company on the global market companies continuously must adapt to the future and keep track on the market. Companies must have a high standard for quality and a competitive price to stay in the game. For this to be possible the operation always must analyze to see where improvements can be realized, where to scale back and where to invest, in order to be sure that everything is working as efficient as possible. As for an innovative company as K Hartwall, the engineers who design and develop the products have a big impact on the company's reputation on the market. Products of high quality that work well leads to customers return and for the gaining of new customers. Studies show that the design engineers have the largest impact on the final cost of a product. If they are able to design a product that is cheap to produce and still have the high quality that is required, they have a product that will be competitive on the market and be more profitable for the company.

To provide methods and techniques for the engineers to use so that they can be the best engineer, even if they might not be the most experienced, is an important investment for a company. This thesis is to investigate what possibilities there are for K. Hartwall if they would implement DFMA methods that have a large track record of producing efficient results regularly.

1.2 Objectives

The aim for this thesis is to investigate the possibilities for K. Hartwall to implement DFMA methods into their product design and product development stage. The study will be conducted as a case study in order to be able to see the potential of these methods. The main objectives for this thesis are:

- To analyze one of K. Hartwalls existing roll-cage products
- Modify the product according to the DFMA methods for a more cost-efficient design to produce

- Calculate the cost and time savings done in new design

The goal would then be for K. Hartwall to use this thesis as a base and determine what possibilities there are for further implementations of these methods to their product development and manufacturing efficiency.

1.3 K. Hartwall Oy Ab

K. Hartwall is a family owned company that was founded in 1932 in southern Sipoo, Finland. After almost 90 years the company is still operated by the same founding family with Jerker Hartwall as CEO who took over the position from his father John Hartwall. During the 90 years they have grown to a market leading company globally and have customers in more than 60 countries. Today they have 210 employees mostly located in southern Sipoo, Finland, where the head office and their own production facilities are.

K. Hartwall´s 90 years have grown them to a leading company in shipping and logistic solutions. 1932 they started by manufacturing the wire bottle cap for the Finnish bottle industry. The most common product that regularly can be seen is their roll-cage that they developed in 1985 together with ICA, and today there are many different versions of it. Today they make much more than just the roll-cage. They produce different dollies, flower shelfs, smart cubes, different dairy carts and a tugger-train called LiftLiner. Their three main business areas of expertise are automotive, Retail & FMCG and Postal & Parcel. Their products are actively used by companies such as Coca Cola, Volkswagen, BMW, Carrefour, Royal Mail, Inex Partners, Amazon and Bosch just to name a few. More about the company and their products can be found on their web page: www.k-hartwall.com. (K. Hartwall Oy Ab, 2020)

Figure 1-1. K. Hartwall Oy Ab logo

2 LITERATURE REVIEW

2.1 Product development and manufacturing

2.1.1 General

Product development is something all companies do one way or another both when coming up with a new product and when rethinking something that already exist. For a company that sells a service it might mean to refine an experience or if it is a software to debug a system in order to work smoother. For companies with a physical product it is to make sure that the product is relevant to the customer's needs and make sure that the products stays up to date with time. New technology in one area can indirectly affect a whole other area. For a company like K. Hartwall it is no different.

2.1.2 Traditional methods

Traditional methods of product development and manufacturing of products have been slow and costly. Traditionally, the beginning of a product's life started with the product development, where the design engineer came up with the design of the product and then gave it to the manufacturer who then had to make whatever the design was. This traditional method is called the "over the wall" method because the designer and the manufacturer never actually communicated during design process. Instead the designer

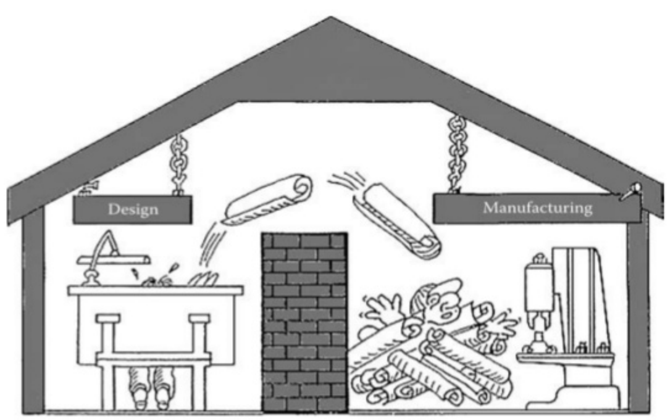

Figure 2-1. "Over-the-wall" designing, historically the way of doing bussines (Boothroyd, et al., 2011 , p. 9)

designed and the manufacturer built what the designer had designed, and once the manufacturer realized that the design did not work, he had to go back to the designer with the issues in order for him to make changes. This process then repeated itself over and over again until the product was done, which made it a very time-consuming process.

Designing guidelines from before DFMA came around were called "producibility guidelines" and they stated that components should be made as cheap as possible. If there is a complicated component with complex shapes or angles, the part should be divided into separate components with a simpler design, which at a later stage could be assembled to the complicated component. As an example, a sheet metal part with edges that needs to be bent both up and down the producibility guidelines would suggest that the component is divided into two parts, the bending upwards in one component and the bending down in a separate part and then after this attach them together with something like a rivet (Figure 2-2). When assembly cost is excluded a component like this can be up to 50% more expensive when taking to account the fact that two different expensive tools needs to be made when following the producibility guidelines. (Boothroyd, et al., 2011)

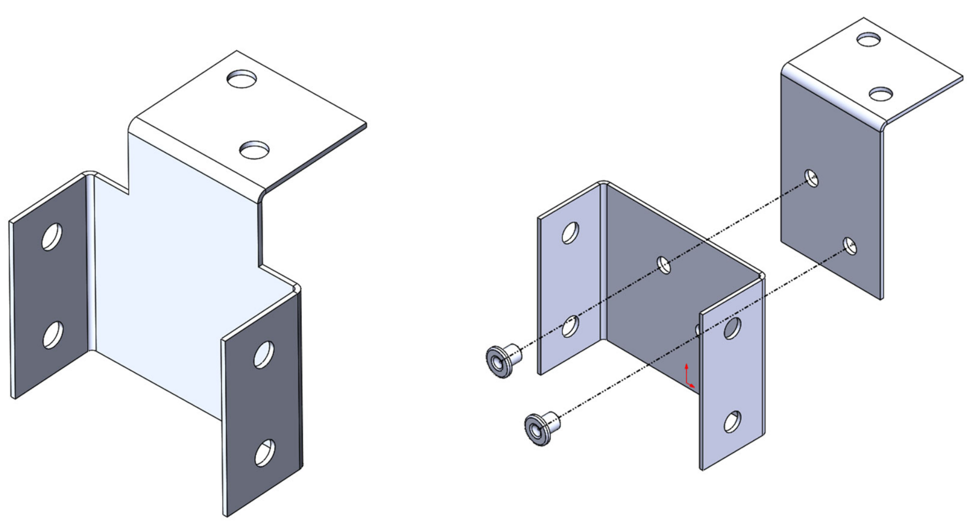

Figure 2-2. To the left the required component and to the right how it would be designed according to producibility guidelines.

2.1.3 Different methods

2.1.3.1 Design for Manufacturing and Assembly

Design for Manufacturing and Assembly (or DFMA) are ways and methods to use and think about during the early to mid-stages of product development. The idea behind DFMA is that the traditional method of product development, as mentioned earlier, is inefficient and basically states that more can be saved if a more complicated component are used, since there then would be less parts to work with at the final assembly stage. This will save time instead of material cost, which in the end will save more money for the manufacturer.

For DFMA to be possible the designer needs to have knowledge of how manufacturing works and which methods are costly versus cheap. When the designers have knowledge of manufacturing and keep it in mind when designing, they can design a product that is much cheaper and easier to produce, even more complex parts. The designer also needs to communicate with the manufacturer during the process so that the collaboration is better than the "over-the-wall" method as mentioned earlier. DFMA is the technique that will be focused on in this report. (Boothroyd, et al., 2011)

2.1.3.2 Lean Six Sigma (6σ)

Lean Six Sigma are tools for making the product manufacturing more efficient. The tools are a combination of two different methods that were combined and refined by Toyota and then implemented by companies like Motorola, General Electric, Nokia and many more. The two methods that were combined were Lean manufacturing and Six Sigma quality.

Lean manufacturing were methods for making manufacturing more streamlined and Toyota's way to identify and eliminate all elements that did not create value for the customer. Unnecessary and costly elements in a manufacturing process can be things such as having to wait for components and parts for a long time, producing more products than are sold or having components move around unnecessarily with long transportation distances between production stages. By tuning the manufacturing line so that it make the right amount of everything at the right rate and have a well-planned manufacturing line will be economically beneficial.

Six Sigma quality is a method for making the production quality better. By putting more focus on statistics and quality control, weak processes can be identified and improved. Generally, Six Sigma promotes that less variation in manufacturing processes leads to better results. Six Sigma follows DMAIC process which stands for Define, Measure, Analyze, Improve and Control.

The combination of the methods above is called Lean Six Sigma which means taking the methods of streamlining the manufacturing plant and tuning all component manufacturing to the right speed, as well as keeping track on statistics and regular quality controls in order to know which processes work and which do not work as well. This will eventually lead to more efficient manufacturing. The difference between this and DFMA is that this methodology focuses on manufacturing and not on the development of the actual product like DFMA does. (Lainpelto, 2020)

2.2 Design for Manufacturing and Assembly

Design for Manufacturing and Assembly is a philosophy for the product designers to be more cost efficient in the early stage of product development. In general, the basic idea is for the designers to take the manufacturing part and the final assembly process into consideration in the designing stage. Research has shown that a good designer also has good knowledge of the manufacturing processes, since it will help the designer to produce products that are cheaper to manufacture when the designer is aware of the duration of different processes and what is more costly. A designer who is not as aware of the manufacturing process will struggle more with designing a product which has to be as time and price efficient as possible in regard to manufacturing. (Boothroyd, et al., 2011)

2.2.1 Background and general

DFMA is a result of a research made by Geoffrey Boothroyd who is a professor of Industrial and Manufacturing Engineering and Boothroyd's two colleagues Peter Dewhurst and Winston Knight in the 70's and 80's. One of Boothroyd's first experiments was about differences in the design and manufacturing of several different, but similar, gas flow meters from different manufacturers. Almost all of them had the same base for how they worked but there was a large difference in how they were designed and assembled. This was the start of the Design for Assembly -theories. One example of different DFA solutions in the gas flow meters was a simple fastener that was made in many ways across the different gas flow meters. This experiment led to the first two rules in ease of assembly for a product: reduce number of parts and make the assembly operation as easy as possible. For example, a good solution from DFA's point of view would be some sort of snap-fit joint where two components are pressed together, and it is assembled. The worst solution from DFA point of view would be to have a loose bolt and nut as an attachment because there are many more operations like aligning everything and turning the bolt and keeping the component and the bolt in place.

Another area of research Boothroyd and the team did was in the ease of manufacturing (or often referred to as producibility). The general rule of producibility recommends dividing parts into more parts but geometrically much simpler as described earlier. This conflicted with the DFA's rules of having as few parts as possible. Research showed that fewer components and faster assembly times ended up with cheaper products compared to if a bunch of components are used that all separately were much cheaper to produce. The conflict between the DFA's rules and the producibility rules ended up in the research about the combined topic of design for manufacturing and assembly, or DFMA. (Boothroyd, et al., 2011)

One drawback with DFMA is that it only takes to account the early stages of product development and not the full lifecycle of the product. When the separate components get more expensive also repair and replacement parts will increase. This is something to consider when selling the product. As for any company, and especially for a company like K. Hartwall where maintenance and production of spare parts is an important part of the business. If the separate components get too complex and too expensive the customer might lose interest in your product. It can feel unnecessary to change a complete side of a product if just a small part of it have been worn out that easily could have been fastened with a bolt and easy to change. In this paper the focus will be on only DFMA and not take to account service friendliness explained in this paragraph.

2.2.2 DFMA

The main way to overcome the "over the wall" traditional method of manufacturing is to have the designers and the manufacturers communicate during the designing phase. With an arrangement like this the designer can also get an input on what is easy and fast compared to what can be a costly design. The manufacturer can in a DFMA situation have a little heads-up on what is coming and maybe start preparing for it if possible. When it comes to final stages of design process and it is time to start building a concept, the design should be much closer to the actual final product that will be manufactured. The problem of the traditional methods was that the designer designed what he determined to be the best solution, and once the manufacturer got the design he had to send it back to the designer with a list of things that are not possible to make or that should be changed. Then it would go back and forth like that until both the manufacturer and the designer are happy. It is a very costly and time-consuming way.

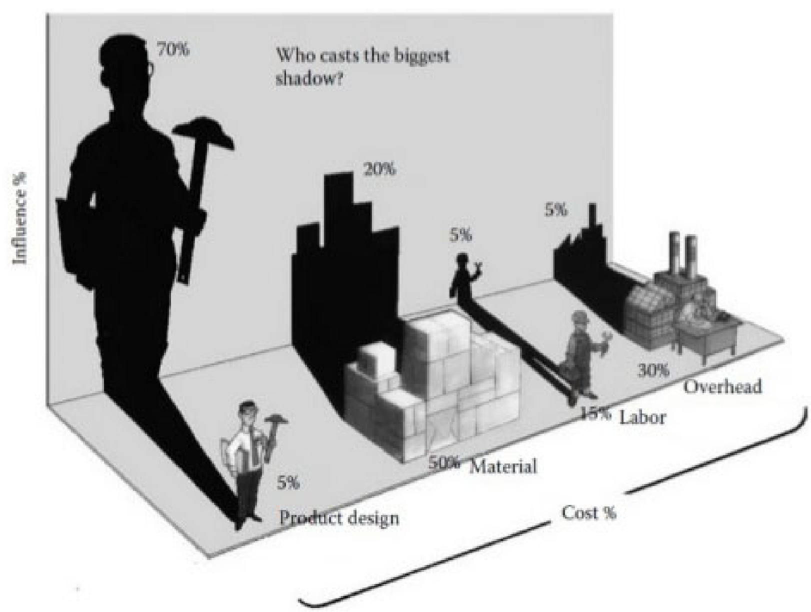

Figure 2-3. Cost influence for a product (Boothroyd, et al., 2011 , p. 8)

Figure 2-3 above is a good representation of "who casts the biggest shadow" compared to what it costs for a company. The visualization is the result of Boothroyd's DFMA research. To clarify what it means the cost bar is the physical cost of what the company the production of a new product. The shadows are the influence a section has on the final cost for the product. The engineer who is going to design the product will have the largest influence on the final cost. Therefore, even if this particular engineer is not such a large part of the final costs, he has the largest impact on what the final cost of the product will be. With a combined cost for the company of 45%, labor and overhead (factory/production line) are a large part of the final cost for producing the product compared to the influence these stages have on the final component. On the other hand, the design engineer is only 5% of the cost for the company but it can influence the final cost up to 70% of the product. This shows the importance of having a good and well-trained engineer on the team because he will keep product prices down and generate more value to the company. (Boothroyd, et al., 2011)

2.2.3 DFA

DFA is the first half of DFMA and it means Design For Assembly. DFA is what to begin focusing on when going through a DFMA process. It basically means that already in a concept stage take into to account how something is going to be built and by having a rough view on what components are needed and how it structurally going to look.

The goal that DFA wants to achieve is to provide methods for accomplishing a simpler but more valuable products. The first aspect is to make sure that the final products' assembly operation is taken into consideration already in the earlier stages of the development, as mentioned earlier. By doing this the risk of focusing too much time on just the functionality of the product and less relevant things that do not bring value to the product should be eliminated and therefore making the production more cost-efficient. DFA also aims to guide the design team to simplify designs both in assembly and parts in order to save cost in both areas. These methods also help to even out the difference with less experienced and more experienced designers.

According to Boothroyd (2011) there are three criteria which a component needs to qualify within. These criteria will help to determine whether parts of the product should be combined with other parts or if they should be eliminated completely. Boothroyd's (2011) three criteria for component elimination are:

- If a component does not have to move in relation to other parts

- If a component does not have to be of another material or be isolated, the component should be eliminated
- If a component must be assembled separately, since otherwise unnecessary assembly or eventually some disassembly would be needed

In the case of a DFA analysis it means that a product is analyzed component by component to see if everything is necessary or not. The goal here is to eliminate components that are unnecessary or if there is a possibility to combine it with another component. As mentioned earlier, Boothroyd's research showed that less components means less assembly time and therefore the cost of the assembly stage will reduce. At this stage of a DFA analysis all bolts, nuts and screws are analyzed to see if there could be any other solutions. (Boothroyd, et al., 2011)

2.2.3.1 Design guidelines for manual assembly

In the early stages when designing a product, the designer needs to know who is going to build it and how it is going to be built. According to DFMA, there are slightly different design guidelines for different assembly methods. There are different aspects to consider if a product is designed for manual assembly with a person bolting it together, if its final stage is welding or if there are robots doing all the work. In K. Hartwalls case they have manual assembly where there are people that assemble bolts and everything together. Therefore, DFMA guidelines for manual assembly will be the main focus of this paper.

There are two things to consider when having manual assembly. The first is **design for part handling**, where the goal is to avoid designing parts that are hard or dangerous to handle. Parts that are considered hard to handle are parts that are small, since it makes them hard to pick up or are complicated to position in the assembly. Parts that are sharp or in other ways can hurt the assembly person are considered to be dangerous. Extra safety precaution or positioning takes more time, which in the end leads to more cost. The other area of manual assembly is *design guidelines for insertion and fastening*, which means that components should be designed so that inserting bolts, springs, or something else goes as easy as possible. Examples for design handling, insertion and fastening can be found in the appendix (Figure 8-1 to Figure 8-13). Following is the guideline listed.

Design Guidelines for Part Handling:

1. If possible, design parts that are end-to-end symmetric. If not possible, then maximum possible symmetry (Figure 8-1a)
2. When parts cannot be symmetric, try to make it clearly asymmetric for easier assembly. (Figure 8-1b)
3. Include features in design that can prevent jamming when the part is stacked, or some other way stored in bulk (Figure 8-1c)
4. Avoid features that makes it possible for a part to tangle when stored in bulk (Figure 8-1d)
5. Avoid parts that stick together or are slippery, fragile, flexible, very small or very large, or that are hazardous to the handler. (Figure 8-2)

By using these guidelines in the product development, the assembly will be faster and easier for the person assembling the products manually. The time it takes for him to, for example, untangle a C-rings or position a tiny pin in a hard to reach hole is an unnecessary waste of time. As shown in Figure 8-1b it makes it much easier for the assembly person to see which direction the plate goes if the holes in the plate are not symmetrical.

The previous list applies for parts in general, and the following guidelines are specific guidelines for parts that are inserted into something or used as a fastener of some sort. By following these steps aligning holes and choosing fasteners should make the process easier and faster.

Design Guidelines for insertion and fastener:

1. The design of a part that is to be inserted should have as little resistance as possible and use chamfers to guide the inserted component into place. Enough clearance should be used but not too much so that it gives room for a component to turn and not jam (Figure 8-3, Figure 8-4, Figure 8-5 and Figure 8-6).
2. Standardize parts by using common parts, processes and methods over as many models and products as possible. High volume processes usually reduce production cost (Figure 8-7).

3. Use pyramid assembly — to consider progressive assembly about an axis as reference can make assembly easier. With help of gravity and assembly from above is generally best (Figure 8-8).
4. Avoid, if possible, to design components that needs to be held down or in place when it is assembled. Also avoid loose parts that need aligning, like a washer that needs to align with a hole, try to include self-locating features into the component (Figure 8-9). If holding in place or holding down is absolutely necessary, try to design it to be secured as soon as possible.
5. Try to design so that a component is in position before it is released. If not possible then design some guiding design that will make sure it does not jam and always falls into place without problems. (Figure 8-10).
6. When using mechanical fasteners, consider the cost and installation time of the processes. Listed below are fasteners listed in order of cost with snap fitting as the cheapest option (Figure 8-11):
    a. Snap fitting
    b. Plastic bending
    c. Riveting
    d. Screw fastening
7. If possible, avoid the need for repositioning the product during assembly. Like inserting components from different directions might require turning the product around during assembly (Figure 8-12).

An important notation about the rules above is that the rules cannot be listed in any order of importance since they all can be equally important. It depends on the product, for one product changing every fitting to snap fits will be the most efficient and for another part snap fits can make the product cost more. There is not really any way to exactly say how much will be saved by doing some changes without testing. These are more general guidelines that have come up in research and data gathering as key features that will help with cost saving. In the end it is up to the designers to know their products and use these guidelines to further reduce cost on what they work on. (Boothroyd, et al., 2011)

2.2.4 DFM

The second part of DFMA is Design for Manufacturing, or DFM. This part came about when Boothroyd came to the realization that DFA guidelines was the opposite from and conflicted with the traditional producability guidelines that were explained earlier. No value would be gained by reducing components if the new components were a lot more expensive. DFM is used to educate the design team on manufacturing in order for them to figure out which processes are time consuming, hard and costly compaired to processes that are fast and easy. For this stage to work even better the manufacturer should be included in the design process. This arrangement would lead to a more collaborative system where the manufacturer can give comments on what might work and what might not work already during the early stages of design. By going for a DFM collaborative system rather than the traditional "over the wall" system the result should end up to be a much more completed product already in the consept stage.

In the case of an DFMA analysis like this paper, the DFM stage is to do a cost evaluation of the new design. By calculating the manufacturing price for the new design's components, the success of the DFA analysis can be determined. The combined manufacturing cost of the new component does not necessarily have to be lower than the cost of the old design, as long as the new cost does not exceed the savings made in the DFA stage of an DFMA analysis. (Boothroyd, et al., 2011)

2.2.5 DFMA over other methods

There are many methods for making a company and production more cost-efficient, like Lean Six Sigma mentioned earlier. All of them have their differences, some are more general whereas others are more specific. How DFMA differs from other methods is that it focuses much more on the early stages of development, whereas most other methods focus more on the manufacturing line and efficiency of the production. DFMA is like designing the product itself for an efficient production instead of trying to design an efficient production around a product. (Boothroyd, et al., 2011)

2.3 SolidWorks

SolidWorks is a software for Computer Aided Design (CAD) and 3D modelling. This is the software that is used at K. Hartwall for product design and visualization of products. When talking about CAD software capabilities, SolidWorks is a so-called midrange software. Midrange software means in this context that its main focus is 3D visualization of products but can also be used to a certain degree for structural analysis of materials and Computer Aided Manufacturing (CAM). SolidWorks is one of the most popular mid-range CAD software used in the world and it is also the one software that will be used for redesigning the product in this paper.

2.3.1 Different CAD software

When it comes to CAD software's can be classified on a scale from low-end software, mid-range and high-end. High-end software's like CATIA and NX Siemens are also 3D modelling software's, but they are more focused on material and component analysis and different kinds of simulations. For example, these software's can simulate fluid dynamics around a boat hull, use it for finite element method (FEM, that is material strengths) or for programming a machine with CAM functions. These high-end software's are more common in automotive, aerospace and ship building industries where the analysis of the design is more important than the visualization of it.

When talking 3D design, a low-end software is one that in most cases only has the possibilities to create a 3D design that then can be used for a 3D printer or something similar. After a component is created it still have to run through a special software to prepare the model for 3D printing. These software's only goal is to visualize the component, and in most cases, material properties cannot be added or do any kind of analysis of the part. All "free to download" and open source 3D design software are low-end software's.

2.4 K. Hartwall and Product Development

The product development at K. Hartwall from the start of a new project to the production can be divided into four phases. After the team for the new project is decided the first phase can start. One way for a new project to start is by request from a customer who wants to modify an existing product or needs a completely new solution. A new project can also start internally. This can happen when a gap on the market is realized or for example when going into a new country a product can be modified to fit that market's needs.

Phase one can be called *concept phase*, and this will begin with a kick-off session where the schedule, the budget and the goal with the project are determined. After the kick-off session some designers are starting to work on a couple of concepts to have different options to show the customer. After a concept has been approved both internally and by the customer, a preliminary production plan and price estimate is made. When the concept and cost is accepted by the customer, the project moves forward to the next phase.

Phase two can be called *design phase*, and during this stage the complete design is made, and concepts are built to make sure they work. During testing of the product material sourcing and planning of the production are also taking place. In this phase the shipping logistics are planned in order to know if it will be shipped fully assembled or if the final assembly is done at the customer. As a last stage in this phase the sample product is sent to the customer for testing in their facilities and for them to give feedback on it after having hands-on experience with it. Most of the product development is done in the two first phases.

Phase three can be called *offering approval of design*. In this stage detailed planning and setup of production is done. The larger fraction of this phase is to get prices for material from suppliers, making detailed cost calculations of the product and giving an offer to the customer.

Phase four or production phase is the final and *last stage*. Here the product is already done, and the customer has bought the product. This stage starts with making sure that all drawings for the components are up to date so that the manufacturer knows what to do. One section of this phase is dedicated for a drawing preview to make sure that mistakes are spotted, therefore making sure that misunderstandings will not happen. (K. Hartwall, 2020)

3 METHOD

This research will be performed as a case study on one of K. Hartwalls products. The product will be analyzed and based on the DFMA theories explained earlier also modified. By analyzing and modifying the product, cost savings can be calculated. This research can then be used by K. Hartwall to determine what possibilities there are to widely implement DFMA into their product development.

3.1 Why case study

Case studies are in general a good way to do exploratory research where new ideas can generated. Case studies are also a good way of illustrating the possibilities for further research in a topic. If the case study pays off, the decision to continue and to do a more extensive study on the subject can be made. If the case study does not pay off, the topic can be excluded without putting too much money and effort into it. (McLeod, 2019)

K. Hartwall requested a case study to be done in order to see the possibilities for further investigation and eventually implementation of DFMA in their own product development. Since many products in their product range have many similarities, this would be a reliable way of exploring all possibilities.

3.2 The case study

3.2.1 How the research will be performed

The research will be executed as a case study of one of K. Hartwall's products. The first part of the research will be a DFA analysis of the product. By following Boothroyd's principles of minimum parts criteria, the product will be analyzed component by component. After the first analysis of the components is done and all potential modifications are identified the modification process will start. By following these rules, the product will be analyzed component by component. If there are any possible changes or possibility to eliminate, change or combine parts it will be done at this stage. Other case studies have been executed in a similar way (Harlalka, et al., 2016). The possible changes will be done using SolidWorks because that is the software that K. Hartwall uses and the product is designed in that program.

In the following section Boothroyd's principles of minimum parts criteria are listed:

1. Does the part have to move? If the part does not have to move in relation to other parts around it the part should not be separate. According to Boothroyd even parts that should have small movements could be eliminated with solutions that involves elastic material.
2. Does the part have to be made from other material? If the part does not have to be isolated or in other ways be separated from the rest of the assembly, the part can be eliminated.
3. Is the part in the way of other assembly? If assembly of some other part is impossible when the part in question is in place, it can either be made as a separate part, otherwise it should be eliminated.
4. In some research and other case studies as a fourth requirement has been that the part can be a separate part if it forms the base of the product. In this research shipping possibilities will be taking into consideration that everything large such as walls have to be separate due to ease and cost-efficient shipping.

When the redesign stage is done and all components that could be modified and everything unnecessary has been eliminated, the next stage can begin. The next stage of the study is to perform a time analysis of the new and old design. The time analysis is to determine the theoretical assembly time for the old and new design. For the theoretical assembly time Boothroyd has certain tools that will be used. Using Boothroyd's tools the old design can be compared to the new design and see if any saving has been achieved.

When there is a price on the assembly a DFM analysis can be executed. A DFM analysis is to determine the manufacturing cost of the components in the product. By adding the manufacturing cost to the assembly cost, the total production cost of the product can be calculated. For the research, the manufacturing cost of the old and new design needs to be calculated to determine the success of the case study. The manufacturing cost calculation will be performed by a professional at K. Hartwall.

As a final step in in the case study the DFM analysis is added to the DFA analysis of the old and the new model. After that, the results can be compared and it is possible to see how successful the DFMA study was. The manufacturing cost of the new product itself does not have to be lower than the old one, as long as the combined DFA and DFM are. (Boothroyd, et al., 2011) (Harlalka, et al., 2016)

3.2.2 The product

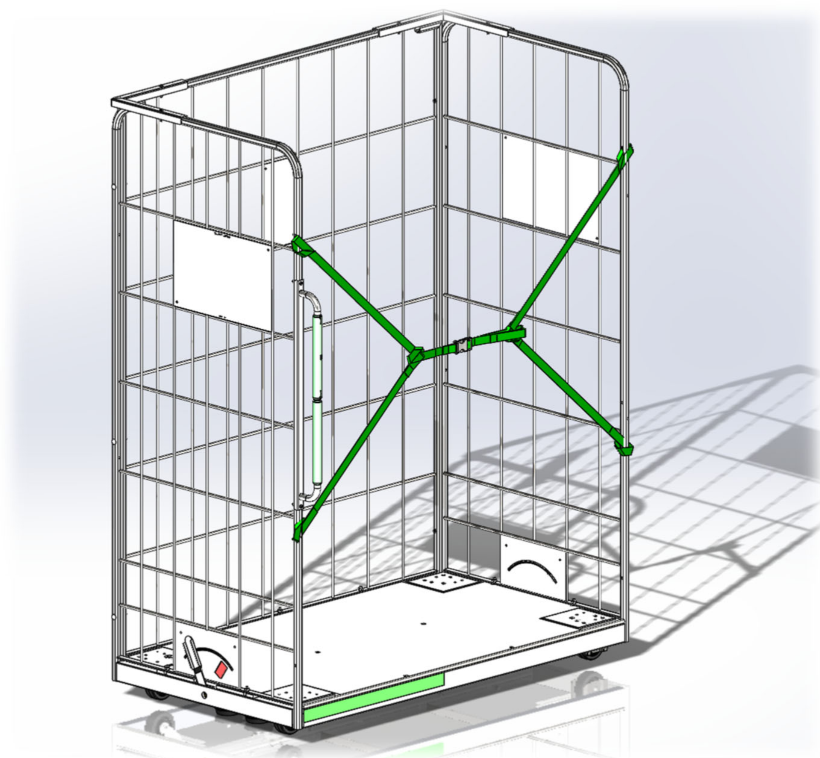

Figure 3-1. The Roll-Cage that will be analyzed in this case study

The product that will be analyzed in this case study is a large roll-cage that is designed specifically for a large online retailer that have distribution facilities all over the world. The dimensions of the roller cage are 1422 x 800 x 1874 mm and has two fixed wheels in one end and in the other end there are two swiveled wheels that can turn 360°. The product has three fixed walls and one open side. All three walls are bolted together and to the chassis by using bolts. The floor is made of a honeycomb-reinforced plastic panel. The roller cage has a brake system that is activated with a leaver on both shorter sides.

The leavers are connected to an axis that runs across under the floor. The axis connects to an arm that pushes brake buffers made from rubber against the floor. There are red and green stickers behind the leaver to indicate if the brakes are activated or not. If the red sticker is visible it means that the roll cage cannot move. The braking system itself is in the same end as the swiveled wheels.

3.2.3 Parts and component

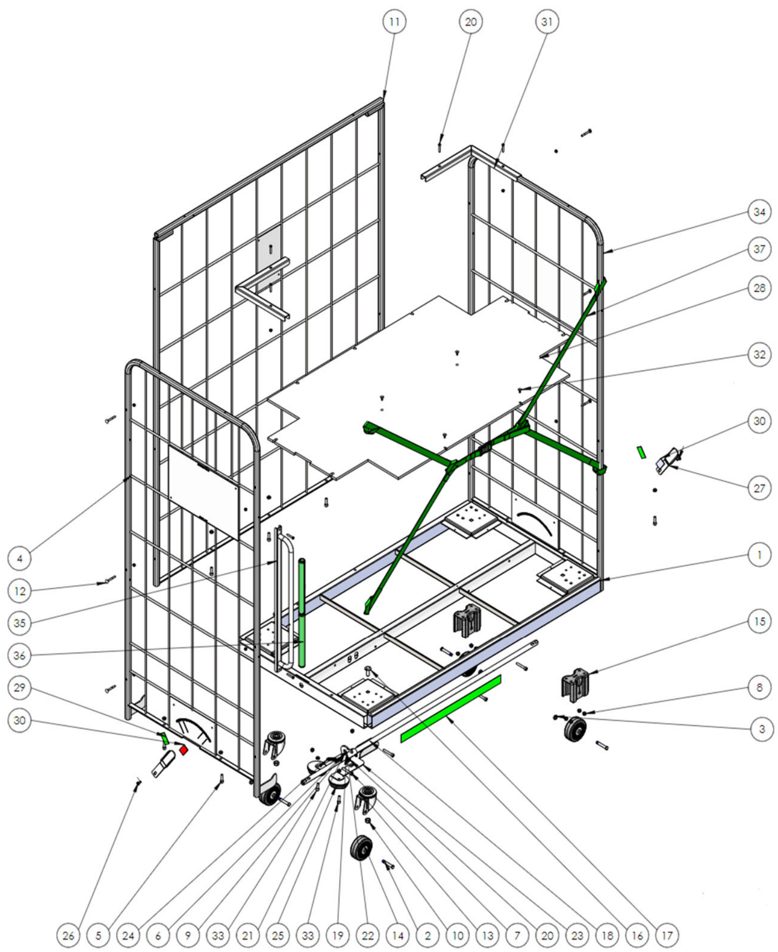

Figure 3-2. Exploded Roll-Cage with component numbers

Following is a list of all the different components of the product. In this case study the sub-assemblies will not be taken into consideration. In the list below all 37 different components and how many there are of each component are listed. There are 116 different parts in total that build up the entire product. The rows of all standard components, like bolts, nuts, and washers, are highlighted with gray in the table. The standardized components cannot be modified, they can only be removed or replaced. The white rows in the table are parts that can be removed or modified as much as needed. In the last column of the following table are comments on what modifications can be done to the component for achieving the goal of the case study.

Table 3-1. List of the products components

Part nr	Amount	Description	Possible changes
1	1	Chassis	• Change design of center tube and eliminate guiding bolts for brake axis. • Include the floor into the design of the sub-assembly to re-duce components in the final assembly. • Include rivets with treads where the walls can be attached to. • By welding the forks less operations and moving around this component is needed in assembly.
2	4	Bolt M10x60	For maintenance purposes the wheels must be removable
3	4	Nut M10	For maintenance purposes the wheels must be removable
4	1	Left side	• Attach the handle instead of having it as a separate part. • Make the wall bolts locking
5	7	Bolt M8x30	Short bolts have makes harder to assembly according to **Error! Reference source not found.**, can be replaced with treads integrated to floor or replaced with rivets.
6	1	Bolt M6x25	
7	4	Bolt M8x50	
8	21	Nut M8-8	
9	15	Nut M6-8	
10	2	Nut M12-8	
11	1	Backwall	
12	6	Bolt M6x50	
13	2	Swivel fork	
14	4	Wheel	
15	2	Fixed fork	Could be welded to the wheel plate. (8 less bolts)
16	2	Bolt M12x35	
17	1	Tape, Green, 40 x 600 mm	
18	1	Axle	Can be modified so that less bolts are needed for the brake system
19	1	Bracket	
20	8	Bolt M6x35	-4 bolts
21	1	Washer	Has to stay for function reasons
22	1	Ball Bearing	
23	1	Bracket	
24	1	Spring	
25	2	Buffer	
26	2	Bolt M6x16	
27	2	Brake pedal	
28	1	Deck	Could be integrated with the wheel plates into the chassis frame. Would reduce components and rivets.
29	2	Sticker	
30	2	Sticker	
31	2	Support	Can be removed because it does not meet Boothroyd minimum part criteria, means four less bolts and four less nuts
32	4	Rivet 4,6x16	
33	2	Bolt M8x25	
34	1	Right side	Can be modified to fit locking bolts.
35	1	Handle	Could probably be welded to the side wall and then at least two bolts and nuts could be reduced.
36	2	Steering handle	Can be removed because it does not meet the criteria to be a separate part.
37	1	Strapping	
tot	116		

The largest components are the walls and the chassis. They are all sub-assemblies that are welded together in an earlier stage. Because they are welded with robots the possible savings are quite small considering the possibilities in manual assembly.

In the last column the possible changes are listed. Priority one is to get rid of as many bolts and nuts as possible because according to Boothroyd's research those are the ones that are the most time-consuming actions to fasten in the assembly stage. If the bolts themselves cannot be eliminated an attempt to find a less time-consuming alternative of bolt or bolt-nut combination should be made. According to Boothroyd different bolts have different fastening time (Figure 8-15, Figure 8-16 and Figure 8-17).

3.2.4 Analysis of changes

Error! Reference source not found. below is the updated version of the product. It has been reduced from 37 different components to only 31, and the total component amount has been reduced from 116 components in the top level assembly to only 69, of which most eliminated components are bolts and some nuts. Bolts and nuts are the most time consuming parts in an assembly because all the allignment of different components and holes have to be done before aligning the tools with the bolts and nuts.

The largest physical change are the changes done to the chassis. The floor panel was changed into another material and was included to the chassis. Additionally, all seven bolts and all rivets that were holding the other components to the chassis were eliminated. The change also eliminated the wheel plates from the sub assembly which made the chassis a much simpler component. By further welding the fixed wheel fork to the chassis eliminated additional eight bolts in the final assembly. The changing of the chassis to a single and simpler piece to assemble led to 10 kg weight increase. However, with the various smaller reductions in the rest of the design, the final weight increase was less than 10 kg. Since the chassis from the beginning is an over 60 kg heavy piece, the small weight increase is not that significant. Other significant changes could also be made in the breaking system, which is located underneath the chassis. Some bolts where eliminated

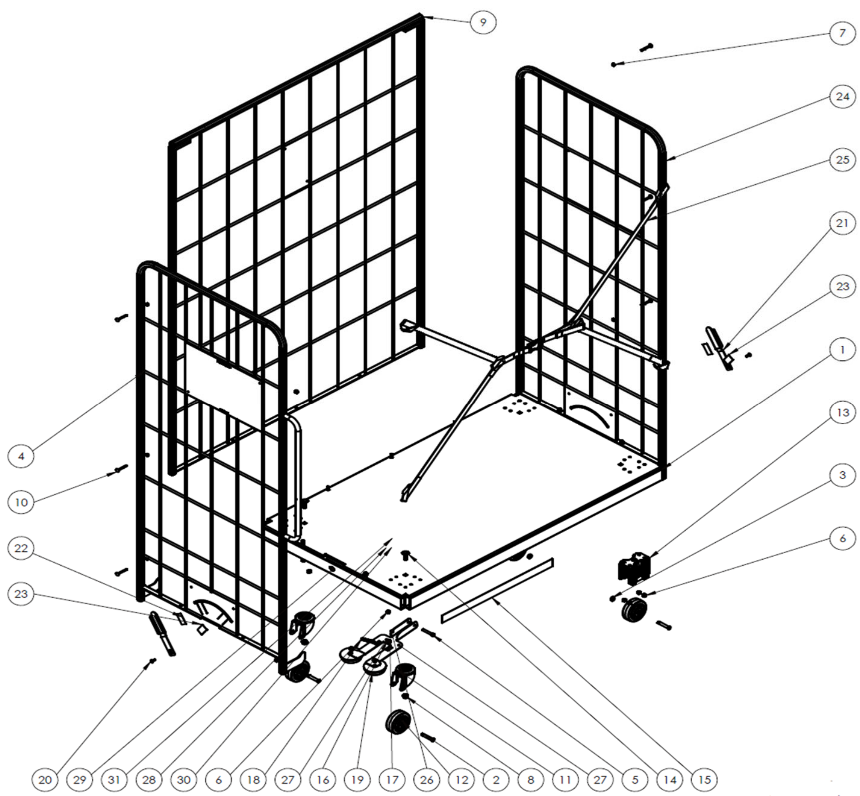

Figure 3-3. Changed exploded view

in thight plases which also saved lots of time. Instead of bolting the brake system to the axis underneath, slots for it to fit into were added with less bolts than previously, while still keeping its functionality. Visually it does not look like there were any changes, because the majority of the changes were small and invisible from above.

Following Table 3-2 and Table 3-3 is the calculation of how much time is spent on handling the assembly and inserting a component to the assembly. The first table is a table of the old design and the second on a table of the new design. Both are made in the same way with the same principles. They are based on Boothroyds DFMA methods of how long a task takes (Figure 8-13 and Figure 8-14). Column one represents the component number, column two shows the part's name and the third column shows the amount of each component. Colum four is the geometrical properties and allignment of the component as explained in Figure 8-18. Column four and six are classifications of what kind of insertion it is about, acording to Figure 8-13 and Figure 8-14 and column five and seven is the time it takes for move around that component. The ninth column shows the total handling and insertion time, and the very last row shows total time for all parts.

Table 3-2. DFA analysis before changes

	Part Name	Number of parts	α + β	Manual Handeling code	Handeling Time (s) per item	Manual inerting code	Inserting time per item	Total operation time (s)	Description
1	**Chassis**	1	Heavy	99	9	59	12	21	Base for hole component
2	Bolt M10x60	4	450	14	2,55	48	8,5	44,2	
3	Nut M10	4	360	14	2,55	48	8,5	44,2	
4	**Left side**	1	Heavy	99	9	59	12	21	
5	Botl M8x30	7	360	14	2,55	48	8,5	77,35	
6	Bolt M6x25	1	360	14	2,55	48	8,5	11,05	
7	Bolt M8x50	4	360	14	2,55	48	8,5	44,2	
8	Nut M8-8	21	360	14	2,55	48	8,5	232,05	
9	Nut M6-8	15	360	14	2,55	48	8,5	165,75	
10	Nut M12-8	2	360	14	2,55	48	8,5	22,1	
11	**Backwall**	1	Heavy	99	9	59	12	21	Wall, importent for function
12	Bolt M6x50	6	450	14	2,55	38	6	51,3	
13	Swivel fork	2	540	24	2,85	41	7,5	20,7	
14	**Wheel**	4	360	14	2,55	40	4,54	28,36	Wall, importent for function
15	Fixed fork	2	540	24	2,85	41	7,5	20,7	
16	Bolt M12x35	2	450	14	2,55	38	6	17,1	
17	Tape, Green, 40 x 600 mm	1		-		30	2	2	
18	**Axle**	1	360	93	3	29	11,5	14,5	
19	Braket	1	720	39	4	50	6	10	
20	Bolt M6x35	8	450	14	2,55	38	6	68,4	
21	Washer	1	180	01	1,43	40	4,54	5,97	
22	Ball Bearing	1	180	04	2,18	40	4,54	6,72	
23	Bracket	1	720	39	4	50	6	10	
24	Spring	1	180	81	4,5	41	7,5	12	
25	Buffer	2	360	14	2,55	40	4,54	14,18	
26	Bolt M6x16	2	360	14	2,55	38	6	17,1	
27	Brake pedal	2	720	34	3	30	2	10	
28	**Deck**	1	Heavy	99	9	56	12	21	
29	Sticker	2	360	-		30	2	4	
30	Sticker	2	360	-		30	2	4	
31	Support	2	720	34	3	38	6	18	
32	Rivet 4,6x16	4	360	34	3	56	12	60	
33	Bolt M8x25	2	360	14	2,55	48	8,5	22,1	
34	**Right side**	1	Heavy	99	9	59	12	21	Wall, importent for function
35	Handle	1	720	34	3	38	6	9	
36	**steering handle**	2	720	29	3,7	99	12	31,4	
37	strapping	1	720	39	4	30	2	6	
		116						1209,43	

Stickers and tape are concidered to have no handeling tim acording to Bootroyd.

Table 3-3. DFA analysis after changes

	Part Name	Number of parts	α + β	Manual Handeling code	Handeling Time (s) per item	Manual inerting code	Inserting time per item	Total operation time (s)	Description
1	Chassis	1	Heavy	99	9	59	12	21	
2	Bolt M10x60	4	450	14	2,55	48	8,5	44,2	
3	Nut DIN 936 M10	4	360	14	2,55	48	8,5	44,2	
4	Left side	1	Heavy	99	9	59	12	21	
5	Bolt DIN 912 M8x50	1	360	14	2,55	48	8,5	11,05	
6	Nut DIN 985 M8	10	360	14	2,55	48	8,5	110,5	
7	Nut DIN 985 M6	7	360	14	2,55	48	8,5	77,35	
8	Nut DIN 985 M12	2	360	14	2,55	48	8,5	22,1	
9	Backwall	1	Heavy	99	9	59	12	21	
10	Bolt DIN 603 M6x50	6	450	14	2,55	38	6	51,3	Locking bult
11	Swivel fork	2	540	24	2,85	41	7,5	20,7	
12	Wheel	4	360	14	2,55	40	4,54	28,36	
13	Fixed fork	2	540	24	2,85	41	7,5	20,7	
14	Bolt M12x35	2	450	14	2,55	38	6	17,1	
15	Tape, Green, 40 x 600 mm	1		-		30	2	2	
16	Washer DIN 125A	1	180	1	1,43	40	4,54	5,97	
17	Ball Bearing	1	180	4	2,18	40	4,54	6,72	
18	Spring	1	180	81	4,5	41	7,5	12	
19	Buffer	2	360	14	2,55	40	4,54	14,18	
20	Bolt ISO 7380-2 M6	2	360	14	2,55	38	6	17,1	
21	Brake pedal	2	720	34	3	30	2	10	
22	Sticker	2	360	-		30	2	4	
23	Sticker	2	360	-		30	2	4	
24	Right side	1	Heavy	99	9	59	12	21	
25	Strap	1	-	39	4	30	2	6	
26	Nut DIN 985 M5	1	360	14	2,55	59	12	14,55	
27	Brake	1	720	39	4	50	6	10	
28	Brake	1	720	39	4	50	6	10	
29	Axle	1	360	93	3	29	11,5	14,5	
30	Bolt DIN 603	1	450	14	2,55	59	12	14,55	Locking bult
31	Bolt DIN 603	1	450	14	2,55	59	12	14,55	Locking bult
		69						691,68	

Stickers and tape are concidered to have no handeling tim acording to Bootroyd.

The tables above (Table 3-2 and Table 3-3) show the differences in how much time is spent on assembling the old design versus how long it takes to assemble the new design. Already at this stage there is an almost 40% reduction in assembly time, from 1209,43s down to 691,68s. On top of this there are still additional time penalties added to some actions for what kind of screw head is used and how easy it is to reach or align a bolt.

In Figure 8-15 in the appendix there is plotted out how different bolts are affected by obstructed vision and clearance to other things around it. These obstructions can add extra time when inserting and fastening a bolt or nut. All holes are standard holes and all bolts that do not lock themselves into place are Allan key -heads. Power tools are used to fasten all bolts. The line in the Figure 8-16 graph will be chosen accordingly. The mentioned criteria are true in both the new and old bolts design. Also, all bolts are visible during assembly and therefore graph **b** Figure 8-15 will be used.

Table 3-4. Calculations of how bolts and nuts affect time in assembly (Figure 8-15, Figure 8-16 and Figure 8-17)

Old design					New design				
Bolts		16			Bolts		3		
Clear-ance (mm)	Amount	Timer (s)			Clear-ance (mm)	Amount	Timer (s)		
all over 20 mm		-			all over 20 mm		-		
Allan key head					Allan key head				
Amount	Time (s) per bolt	tot (s)			Amount	Time (s) per bolt	tot (s)		
16	2	32			3	2	6		
Nuts			42		Nuts			24	
Clear-ance (mm)	Amount	Time (s) per rev	Num-ber of revs	tot Time (s)	Clear-ance (mm)	Amount	Time (s) per rev	Num-ber of revs	tot Time (s)
10	10	3,5	9	315	10	1	3,5	7,75	27,125
20	4	2	9	72	20	2	2	7,75	31
30	12	2	9	216	30	12	2	7,75	186
over	28	1	9	252	over	9	1	7,75	69,75
				855					313,875

By combining the result from Table 3-2 where the old designs time is calculated and adding it with the results for the old design from Table 3-4 the total time for assembly can be calculated as done below. Then the same is done for the new design with the result from Table 3-3 and Table 3-4.

$$t_{old}(s) = 1209{,}43\ s + 32\ s + 887\ s = 2096{,}43\ s$$

$$t_{new}(s) = 697{,}18\ s + 6\ s + 319{,}88\ s = 1054{,}18\ s$$

The calculations above gives the assembly time for the old design to be **35min** ($t(min) = \frac{2096{,}43\ s}{60s} = 34{,}9405 \approx 35min$) and for the new design to be **18min** ($t(min) = \frac{1054{,}18\ s}{60s} = 17{,}5697 \approx 18min$). Then by using these two answers the time reduction can be calculated.

$$P(\%) = 100 - (\frac{t_{old}}{t_{new}} * 100) = \mathbf{100} - \left(\frac{\mathbf{2096{,}43}}{\mathbf{1023}} * \mathbf{100}\right) = \mathbf{51{,}5}\%$$

For the product about **70%** of the total products cost is the cost for material, where everything from raw material that is manufactured in-house to parts that are outsourced as well as buying standard components like bolts and nuts. For a cost reduction in this area the best way to proceed is to follow the minimal part criteria and manufacture as much as possible in-house. (Raninen, 2020)

For the production time there is more room for in-house cost savings. When taking to account the calculations done above the theoretical assembly time over the total production time would be about 75% for the old design and only 64% for the new design. By taking the results and combining it with the total manufacturing time the total reduction in production time can be calculated for the part, which later converts into more products produced in a shorter time, which in turn reduces manufacturing cost.

The last stage of this analysis is to conclude the results from the DFA and DFM analysis to get a full DFMA analysis result. The DFM part of the analysis was executed by having the cost calculating department from K. Hartwall evaluate the new design. Some of the new design’s components will be slightly more expensive than the old components, but there are much fewer components in total witch should lead to a similar manufacturing cost. By having K. Hartwall performing this stage, it will give a much more accurate result since they do these kinds of calculations on a daily basis. The cost calculating department came to the conclusion that the new and old cost was almost the same with a **1%** advantage for the new design over the old design.

4 RESULTS

The result will be stated in percentage because exact times, cost and prices will be treated as company secrets.

Thea first step was to analyze the model and reduce de amount of parts and components in the final assembly. The analyzes was made by using the SolidWorks model provided by K. Hartwall. From the original design with 37 different component the new design had only 31 different components. From the 116 separate parts in the original design only 69 parts were left in the new design. All model changes and re-designed parts were made using SolidWorks. The new design was also built as an assembly in the same software.

To summarize all the information and calculating together the assembly time of both the old and new design and by including the manufacturing price the result can be calculated. First the assembly time is calculated away from the total manufacturing time. Then the new time can be added. By comparing the old and the new time the total saving can be determined.

Based on these calculations the new total manufacturing time will be **38% shorter** than for the old design. This means that if one item is produced at a time, the production rate could increase from 10 to 17 over the time of a regular shift. In mass production this would translate to reduction in the cost of the product and shorter time from start to finish of a production batch.

The result from the DFM analysis of the new design done by K. Hartwall, showed that it would be **1% cheaper** to manufacture compared to the old design. This means that the new design is not only faster to produce, it is also slightly cheaper to produce than the old design.

By calculating the time savings into money, the 38% savings is done from the 30% that consists of the labor costs of the total cost. For the manufacturing side there are 1% savings done in 70% of the total cost. When calculating everything together the new design will be **12.2%** cheaper to produce per unit when following DFMA methods and guidelines.

5 DISCUSSION

The 12.2% cost savings is a great result, but it is only theoretical. To begin with, this was only a case study of one of K. Hartwall's many products and not an extensive research that includes other types of products. Therefore, I would recommend to further investigate to see how well these methods behave on other types of products.

Further things that could have affected the accuracy of the result is partially that I am not a trained professional in DFMA and have limited experience with metal components manufacturing. Boothroyd's rules were followed to a large extent so the redesign of the product should not differ a lot should a more experienced person have done the same analysis. Here it is also good to keep in mind that there are as many ways of doing things as there are designers to design it.

The redesign was made purely based on Boothroyd's theories on minimal part criteria and designing rules for an easier assembly. This stage was successfully executed on a theoretical level with a large part reduction. One thing that could affect this from executing the design on a practical level would be K. Hartwall's manufacturing capabilities. Boothroyd states that fewer components will lead to cheaper production even if the components themself are more complex and more expensive to produce. Even if the new design would be perfect on a theoretical level but K. Hartwall would not have the capacity to produce the components and would have to outsource the production of these components, the end result could be a more expensive solution compared to the alternative solution where component are produced in house.

The time calculation where the majority of the savings were done is also theoretical. They are based on Boothroyd's research and are more an average of what it might take. To be certain if that time is accurate is to test it and time it. When it comes to manual assembly there are many factors that can affect the efficiency. For instance, if the assembly personnel has to walk long distances to get components, if the components are not coming to the assembly stage at a perfect rate or if there is a lack of personnel at the assembly stations. These are all factors that can affect the accuracy of the estimated time calculation.

To conclude the discussion is that on a theoretical level these results look great but in order to get a result with the exact accuracy, the results should be implemented and tested. This study has successfully proven that DFMA is something that K. Hartwall should continue to investigate in, because it can turn out to be valuable to implement, which was the goal with this thesis from the very beginning.

6 CONCLUSION

The first objective of this paper was analyzed one of K. Hartwall's existing roll-cage products. This stage was executed well with the use of SolidWorks in which the existing model was designed, where every part and component were analyzed one by one. In this stage about 20 modification opportunities were realized and listed in Table 3-1. New components were designed and old components that needed modifications were modified in SolidWorks. The final products assembly were also created in SolidWorks

The second objective was to modify the product according to the DFMA methods for a more cost-efficient product and to execute the change opportunities that were listed when analyzing the original product. This stage was in many ways successful because the total amount of components was reduced from 116 components to 69 and from 37 different components down to 31.

The last objective of this paper was to do calculations of the new and old designs and then compare them to get a result for the research. The time calculations for the old and new products were executed in Table 3-2, Table 3-3 and Table 3-4 where the result came down to a 38% theoretical time reduction of the total production time. The previous result translates to a 12,2% reduction in the total cost of the product.

To conclude this paper, the case study can be considered a success. When taking into consideration that all objectives that were stated in the beginning of the thesis were successfully executed. The new and old design fulfills the same criteria's, but the new design is built with less components, the theoretical production time is shorter and a theoretical cost reduction was also achieved.

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8 APPENDIX

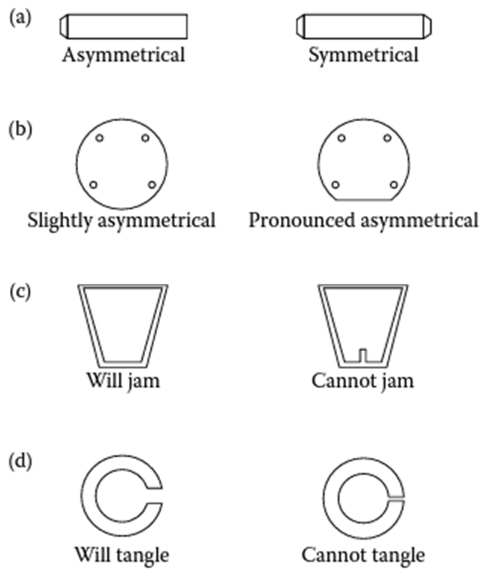


Figure 8-1. Geometrical features can affect handling of a part. (Boothroyd, et al., 2011 , p. 75)

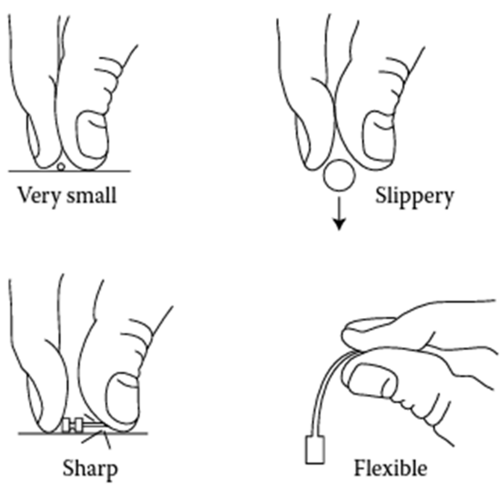


Figure 8-2. Other features that can affect part handling. (Boothroyd, et al., 2011 , p. 75)

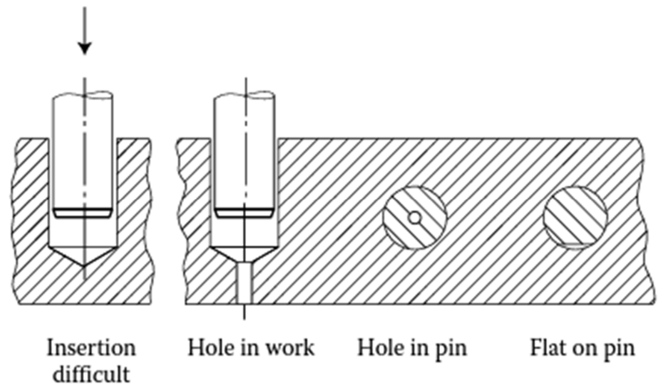


Figure 8-3. Provide air- relief channels for easier insertion into blind holes. (Boothroyd, et al., 2011 , p. 76)

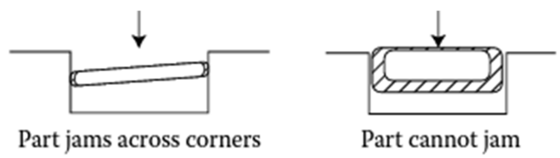


Figure 8-4. Bad design can lead to jamming during insertion. (Boothroyd, et al., 2011 , p. 75)

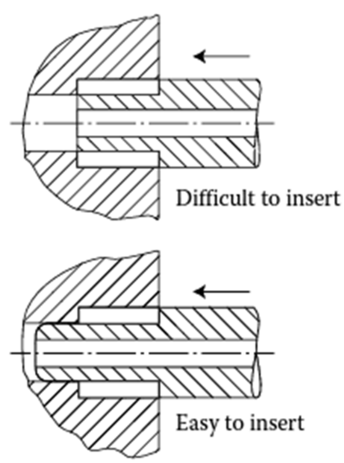


Figure 8-5. Design for ease of insertion. (Boothroyd, et al., 2011 , p. 76)

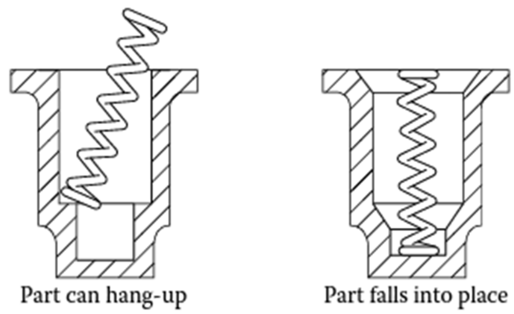


Figure 8-6. Provision of chamfers to allow easy insertion. (Boothroyd, et al., 2011 , p. 76)

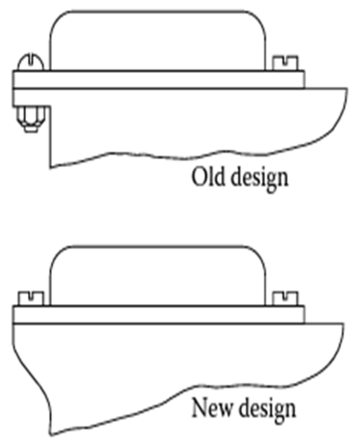


Figure 8-7. Standardize parts. (Boothroyd, et al., 2011 , p. 77)

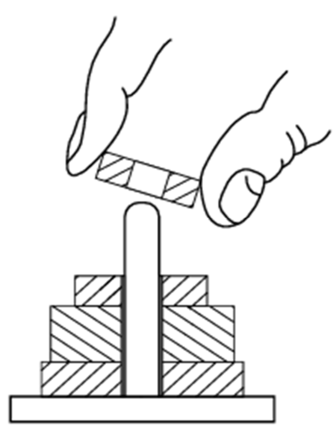


Figure 8-8. Single-axis pyramid assembly. (Boothroyd, et al., 2011 , p. 77)

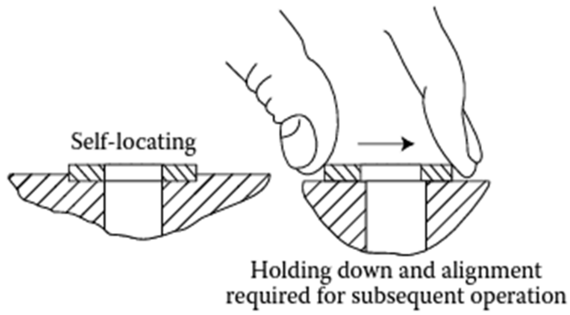


Figure 8-9. Design features for parts to lock in place. (Boothroyd, et al., 2011 , p. 77)

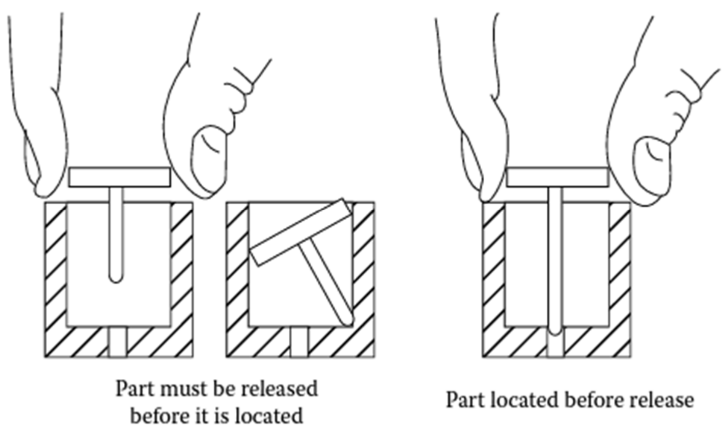


Figure 8-10. Design for easy insertion. (Boothroyd, et al., 2011 , p. 78)

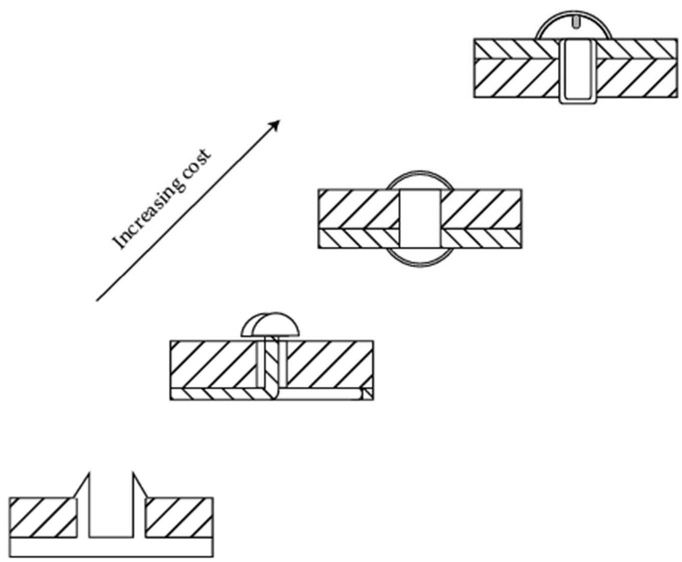


Figure 8-11. General cost for common fasters. (Boothroyd, et al., 2011 , p. 79)

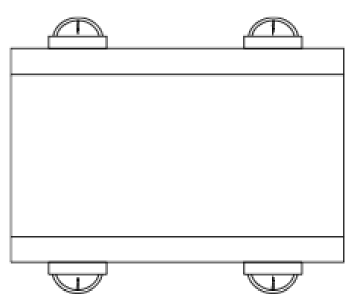


Figure 8-12. Insertion from different sides requires moving around of the part. (Boothroyd, et al., 2011 , p. 79)

MANUAL HANDLING-ESTIMATED TIMES (s)

Key: One hand

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

Key: One hand with grasping aids

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

Key: Two hands for manipulation

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

Key: Two hands or assistance required for large size

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

Notes:

1. Parts can present handling difficulties if they nest or tangle, sick together because of magnetic force or grease coating, and so on, are slippery, or require careful handling. Parts that nest or tangle are those that interlock when in bulk but can be separated by one simple manipulation of a single part; for example, taper cups, closed-end helical springs, circlips, and so on. Parts that are slippery are those that easily slip from fingers or standard grasping tool because of their shape and/or surface condition. Parts that require careful handling are those that are fragile or delicate, have sharp corners or edges, or present other hazards to the operator.
2. Parts that nest or tangle severely are those parts that interlock when in bulk and both hands are needed to apply a separation force or achieve specific orientation of inter-locking parts to achieve separation. Flexible parts are those that substantially deform during manipulation and necessitate the use of two hands. Examples of such parts are large paper or felt gaskets, rubber bands or belts, and so on.

Figure 8-13. Original classification system for part features affecting manual handling time. (Copyright 1999 Boothroyd Dewhurst, Inc. With permission.) (Boothroyd, et al., 2011 , p. 83)

MANUAL INSERTION-ESTIMATED TIMES (s)

Key: Part added but not secured

		Alter assembly no holding down required to maintain orientation and location (3)				Holding down required during subsequent processes to maintain orientation at location (3)			
		Easy to align and position during assembly (4)		Not easy to align or position during assembly		Easy to align and position during assembly (4)		Not easy to align or position during assembly	
		No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)	No resistance to insertion	Resistance to insertion (5)
		0	1	2	3	6	7	8	9
Addition of any part (1) where neither the part itself not any other part is finally secured immediately: Part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
Part and associated tool (including hands) cannot easily reach the desired location: Due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
Part and associated tool (including hands) cannot easily reach the desired location: Due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

Key: Part secured immediately

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

Key: Separate operation

		Mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				Non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				Non-fastening processes	
		None or localized plastic deformation				Metallurgical processes					
							Additional material required				
		Bending or similar process	Riveting or similar processes	Screw tightening or other processes	Bulk plastic deformation (large proportion of part is plastically deformed during fastening)	No additional material required (e.g. resistance, friction welding, etc.)	Soldering processes	Weld/braze processes	Chemical processes (e.g. adhesive bonding, etc.)	Manipulation of parts or sub-assembly (e.g. orienting, fittings or adjustment of part(s), etc.)	Other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	8
Assembly processes where all solid parts are in place	9	4	7	5	12	7	8	12	12	9	12

Notes:

1. A part is the solid of nonsolid element of an assembly during an assembly process. A subassembly is considered a part if it is added during assembly. However, adhesives, fluxes, fillers, and so on, used for joining parts are not considered to be parts.
2. Obstructed access means that the space available for the assembly operation causes a significant increase in the assembly time. Restricted vision means that the operator has to rely mainly on tactile sensing during the assembly process.
3. Holding down required means that the part is unstable after placement or insertion or during subsequent operations and will require griping, realignment, or holding down before it is finally secured. Holding down refers to an operation that, if necessary, maintains the position and orientation of a part already in place, prior to, or during the next assembly operation. A part is located if it will not require holding down or realignment for subsequent operations and is only partially secured.
4. A part is easy to align and position if the position of the part is established by locating features on the part or on its mating part and insertion is facilitated by well designed chamfers or similar features.
5. The resistance encountered during part insertion can be due to small clearances, jamming or wedging, hang-up conditions, or insertion against a large force. For example, a press fit is an interference fit where a large force is required for assembly. The resistance encountered with self-tapping screws is similarly an example of insertion resistance.

Figure 8-14. Original classification system for part features affecting insertion and fastening. (Copyright 1999 Boothroyd Dewhurst, Inc. With permission.) (Boothroyd, et al., 2011 , p. 84)

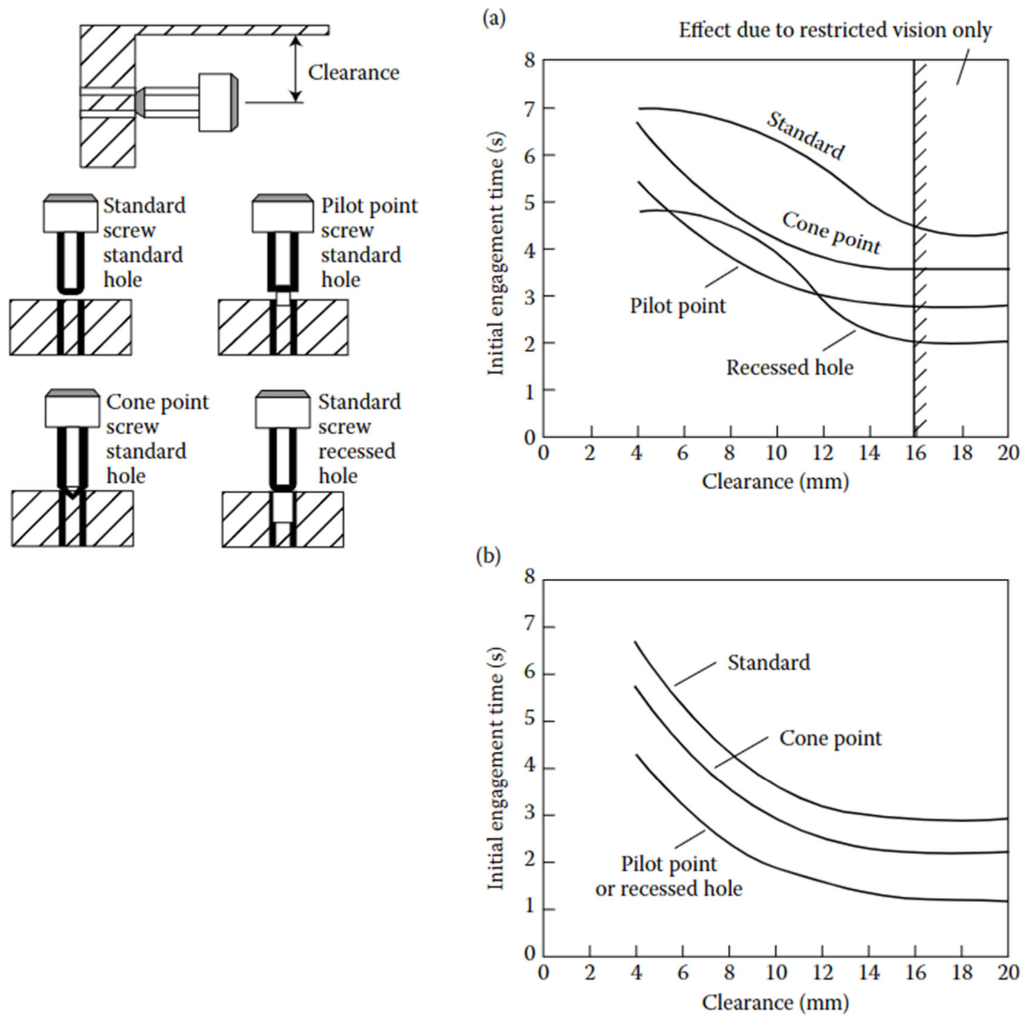


Figure 8-15. Effect restricted access to a bolt or nut have on a screwing operation. a) restricted access and restricted visibility. b) Restricted access only. (Boothroyd, et al., 2011 , p. 98)

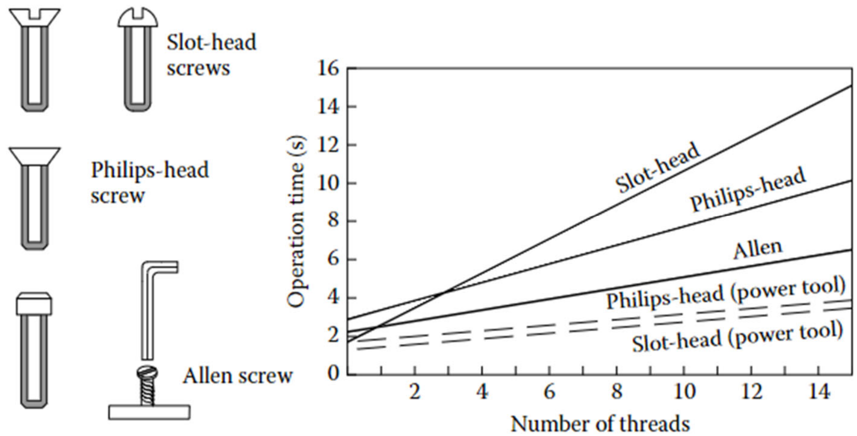


Figure 8-16. The effect of a specific tool have depending on how many threads. (Boothroyd, et al., 2011 , p. 99)

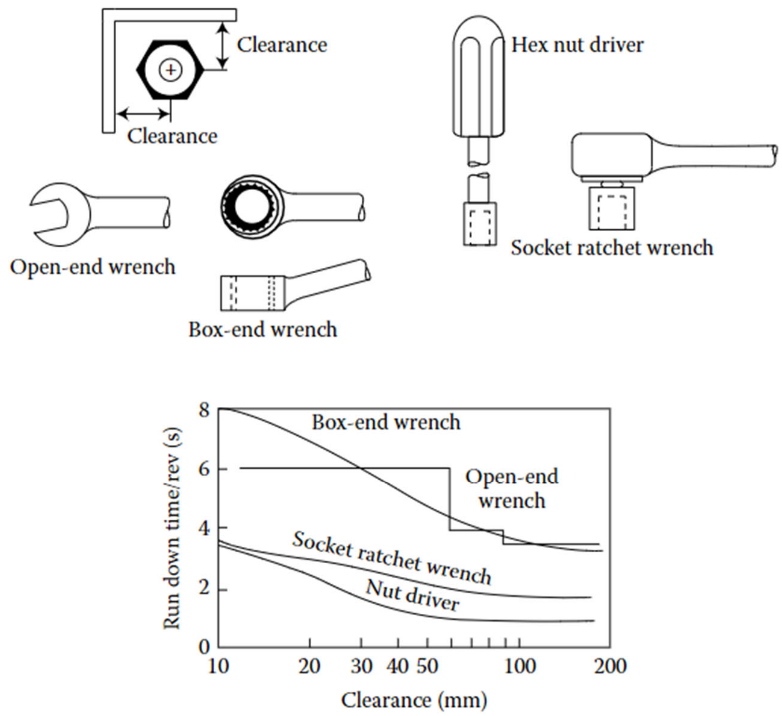
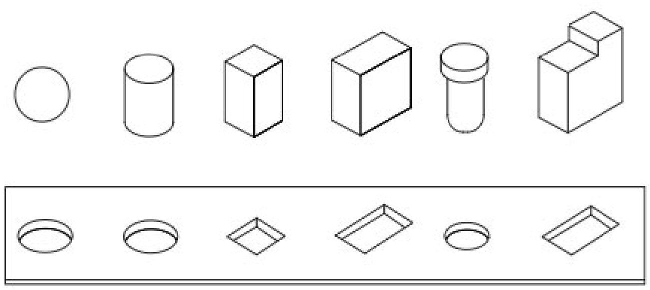


Figure 8-17. Effect an obstacle hhas for certain tool are affected when tightening a nut. (Boothroyd, et al., 2011 , p. 100)



α	0	180	180	90	360	360
β	0	0	90	180	0	360

Figure 8-18. Geometric values with alpha and beta rotational symmetries for various parts. (Boothroyd, et al., 2011 , p. 86)