Contents

1 Introduction

This bachelor thesis consists of 15 credits and is embedded in the program of *Mechanical Engineering* with orientation of *Product Development and Design* at Jönköping University. This thesis has been made in collaboration with Thule Sweden AB at their facility in Hillerstorp, Sweden.

The project that was specified by Thule Sweden AB consisted of the development and presentation of new concepts for the already existing roof mounted bike carrier, Thule Sprint XT. Focus has been on the redevelopment of the mechanism on which the front fork attaches to. The objective was to present mock-ups and visualize the product's functions.

1.1 Background

1.1.1 Company

Thule Sweden AB was founded 1946 by Erik Thulin and is a product developing and manufacturing company, producing transportation equipment. They are the market leader in cargo carriers but also a leading company in the outdoor market. Their goal is to bring people, whose passion in life is outdoor activities, closer to the nature. The products they produce all have the intention to enhance and improve the everyday life of active families and outdoor enthusiasts. The company's beliefs lie within having an active lifestyle regardless of the environment you are in, whether it is city life or remote wilderness.

Thule Sweden AB is part of Thule Group, a company consisting of a collection of brands, all aimed at outdoor activities and transportation solutions. Thule Group is spread worldwide and have more than 4700 points of sales in 136 countries. Thule Sweden AB have their main office in Malmö, Sweden. Their testing Centre is located in Hillerstorp, Sweden, where they also have their production of roof racks as well as an in-house design department. [1]

1.1.2 Design problem

Thule Sprint XT is a car roof mounted bike carrier, included in the Thule Sweden AB assortment. The product is being sold worldwide and gives the user the possibility to mount their bike on the roof of the car, provided it is equipped with a pair of suitable roof racks. At the time of this thesis's beginning, Thule initiated a project with the goal to update, improve and launch the next generation of roof mounted bike carriers. This resulted in the need of producing a new concept for development regarding the Thule Sprint XT. The current design of the front fork attachment were not considered to be optimal. This was because it consisted of many complexed components as well as having a mechanical solution resulting in oblique surfaces. To enhance the product, a new mechanical solution had to be developed. The solution should include these three functions:

- Front fork attachment
- Tightening with equally distributed force
- Give feedback when enough force is applied

Figure 1 close-up on the front mechanism of Thule Sprint XT

Figure 2 Thule Sprint XT mounted unto a car with a bike

1.2 Statement

The majority of bike carriers on the market today are not offering any indicators for the user to understand when the bike is tightened with enough force. Regardless of the amount of experience when it comes to mounting bikes onto carriers, the user is left in the dark considering how much tightening-force that is required. Consequently, the user could either attach the bike with too much force, endangering damaging it, or with too little force which could lead to the bike falling off. Thule Group has developed the Thule Sprint XT, which is the only rooftop fork holder bike carrier available on today's market that provides force limitation feedback. This gives the user feedback of when the right amount of tightening-force has been applied.

Since the market constantly increases the demands on the products being launched, renewal and improvements are always necessary actions. An optimized solution is at all times of outmost interest. This is the reason for Thule to examine their current carriers and motivates the project of the new product launches.

The result that this thesis will provide regarding the product development process can be useful to other interests during their development. A product that does not possess enough quality or durability will have difficulties in competing in today's market where high product standards have become a matter of course.

1.3 Objective and research question

The objective of this thesis was to perform a design process to develop new concepts for solving the mechanical construction in the front attachment point in a bike carrier. The solution to the problem is achieved when the given requirements in the specification are met [Attachment 7, Requirement specification].

This leads to the following research question:

> **How can the mechanism in the front holder of a bike carrier be designed, fulfilling a given requirement specification?**

The research question will be answered when the following three questions are answered:

1. How can the bike be attached to the front of the bike carrier?
2. How can the force that is applied during fastening of the bike be equally distributed on both sides of the fork?
3. How can the user be given feedback when the right amount of force has been applied?

1.4 Delimitations

This thesis was focusing on developing new product concepts and doing this with appropriate methods and approaches of the concept developing phase in the design process. It will not consider the remaining steps in a complete product development cycle, such as adapting for manufacturing and product launch.

Because of time limitation, exhibition of a production-ready concept and prototype was not considered in this thesis. The goal has been to present mock-ups and visualize the product's functions through CAD renderings, as well as simpler prototypes. Physical testing was only done to prove concepts but given standards and regulations have been embossed in the development since they, in practice, had to be met.

Estimations have been drawn through coarse calculations to verify the feasibility of the concepts. The choice of materials has not gone through thorough evaluations and investigations. During concept generation, cost and production viability have been taken into account but no meticulous calculations have been done regarding it.

1.5 Outline

The thesis begins with the *theoretical background*, were the foundation to the theory that have been used during this thesis are explained. This will include the design process that were practiced as well as some design knowledge such as semantics and intuition.

The *method* chapter explains the used methods and their relevance for this study. The methods are written in the order which by they have been implemented.

The approach to the design process and the outcome of the study is presented in the *implementation and result* chapter. When reading this chapter, the reader will gain an understanding of how the product have been developed during the different phases. The final concepts with features and functions will here be presented.

This thesis ends with the *conclusion and discussion* chapter. The discussion includes implications that this study could imply. The conclusions of the result, regarding the met requirements and research questions are presented. The thesis's possibility of what further work that can be done to the project and its viability and reliability are discussed.

The last part of this thesis consists of the reference list and attachments. The attachments consist of picture, figures and other documents that did not fit in the thesis but will give information that could increase the understanding in some sections of the thesis.

2 Theoretical background

This chapter presents and refers to the theories that provides the study with a theoretical foundation. It begins with explaining how the presented theory are connected with the study's research questions. Thereafter it continues with the describing of the theory behind the performed design process and ends with presenting a theory of semantic and intuition.

2.1 Connection between research question and theoretical background

To give this thesis's research question a theoretical foundation, a verified design process with its associated phases are presented. To allow needed process adjustments, a theory about customized design processes, called "*Creativity, trust and systematic processes in product development*" also will be given.

Apart from that, the theory about the design process will give a theoretical background to the subsequent questions as well, the theories about semantics and intuition will further establish this. These theories are described due to that the stages in the design process provides tools and methods to answer the questions. The theory behind semantics offers knowledge about how signs and design interacts with the user. The theory about intuition provides help for decision making during the entire development process.

2.2 Produktutveckling - Effektiva metoder för konstruktion och design

In the book Produktutveckling - Effektiva metoder för konstruktion och design [2], a design process is presented as shown in picture [Figure 3]. The presented process includes stages beginning with creating a strategic plan that will lead to innovation and end with the launching of a complete product. The authors state that this process is iterative and that the different stages could be performed repeatedly during the project. Depending on what kind of project that is performed the amount of stages differs. [2, p. 115]

2.2.1 Pilot study

During a pilot study a problem analysis is performed to gather background information that later can be used in a potential product development project. The analysis should be performed without any preconceptions and premature defined solutions to avoid limitation of innovations and creativity. To maintain an adaptable product development process and avoid unnecessary testing and design work, it helps to include a wide range of competence as early as in the pilot study. Resources are not prioritized during the pilot study nor the concept generating phase. However, a plan on how to distribute these resources in later stages of the project should be produced. [2, pp. 115-116]

2.2.2 Requirement specification

The intention of the product specification phase is to state a specification of what the design process should result in. This is done with the information collected in the previous phase. This should be applied in a way that creates a foundation for later attempts to find a design solution. It should also work as a reference when evaluations for these solutions are done and result in a final concept. Since the understanding and knowledge about the soon to be developed product increases during the design process, the specification will be developed and updated throughout the project. The specification should, in its final state, include all criteria from the explicit and implicit conditions stated in the early process, criteria developed during clarification of the task and those who occur after different design determinations. The criteria should be separated into two different groups. Those who are related to the expected functions of the product and those who limits the allowed solutions of the product. [2, pp. 117-118]

2.2.3 Concept generation

The authors state that the definition of the word *concept* is a first run-up of a solution. This kind of solutions includes a rough layout of the product, cost estimations, illustrations and information about the product's functions, analyses and results from different tests. This phase will not give enough conditions to enable creation of a working prototype, but will on the other hand generate ideas that will lead to the final concept. There are a range of different methods to generate concepts, but the authors mention two categories as the main two. The first category is the *creative methods* which for instance includes brainstorming. The second category is called *systematic and rational methods*. [2, pp. 119-120]

2.2.4 Concept elimination

The concept elimination phase intends to analyze and compare the different solutions against each other and eventually select a concept to continue the process with. The evaluation should rank the concept's values relative to the demands and requirements from the specification. The selection should be motivated by the concept that receives the highest rating during the analysis. Challenges could appear during this phase since different characteristics could be valued and measured differently by different stakeholders. Systematic matrices could be of great help during the selection. Evaluation of specific requirements could however be necessary. Actions such as rough calculations, testing of physical prototypes, modeling or computer aided simulations could in this case be performed. [2, pp. 120-122]

2.2.5 Configuration and detail design

With the previous phases as foundation, the selected concept will now be ready for further development to become a functional product that fulfill the requirements. This phase is focusing on the detail design of the selected concept. This includes: dimensioning, selection of standard parts, design and choice of material and definition of the layout. This phase should lead to a prototype capable of testing, describing the intended product functionality and usability. [2, pp. 122-124]

2.2.6 Prototypes

There are a lot of reasons for creating a prototype and the variety of appearances differs with the purpose behind the prototype. Today, virtual prototyping is a commonly used method for testing and visualizing both function, appearances and performance before any physical prototypes are created. Computer aided prototyping are still not able to replace physical ones completely, therefore companies develop both. Included in the category "*physical prototypes*" are mock-ups. These are made to visualize shape, characteristics and color. Also included are functional prototypes that are tested to verify new technical solutions and those who are tested for production. [2, pp. 124-125]

2.2.7 Adapt for manufacturing

It is essential to adapt the product for manufacturing (DFM). The purpose of the adaptation is to make it possible for the product to be machined and to make sure it caters to the different stakeholders' demands. This needs to be done in a realistic and economic point of view. After this phase, the product should be ready to be launched. [2, p. 125]

2.3 Customized design process

Several attempts to standardize the design process have been made to make the procedure more cost and time effective. The uniqueness that every project requires, makes it difficult to follow a standard process precisely. Companies need to both explore innovation and exploit possessed knowledge when developing new products.

The study *"Creativity, trust and systematic processes in product development"* discusses how a structured working process could disturb a creative one, or the opposite. The conclusion in the study results in a statement that a systematic design process does not necessarily limit the creativity. It is debated whether a balance between the two processes can result in an optimal structured and systematic process that favors creativity. The outcome of the study explains that a structured design process should be considered as an important prerequisite rather than a requirement, which could help the organization with its creativity and add value to it. [3]

2.4 Semantics

Without a correct understanding of a product, the user will experience trouble using it. During the last decade, the importance of semiotic has increased amongst product developers. [4]

Semantics, together with *pragmatics* and *syntax* is a part of the research behind *semiotics*. *Semiotic* is the study of signs. It addresses their meaning, possible combinations and application between product and sign. *Semantics* may be seen as the application of theories on what signs are communicating. There are four ulterior functions of *semantics*: express, indicate, identify and describe. The product should with its design **describe** what it is and **express** abilities. It should be possible for the user to **identify** the product's focus and from what brand it belongs. The product should also be able to **indicate** the function in a way that invites the user to act or react. With a *semantic* approach on an industrial design process the product's use could result in being more obvious and self-evident. [4, p. 13] [5, pp. 52-55]

2.5 Intuition

Hubert and Stuart Dreyfus are writing in their article "*Mind over Machine: The Power of Human Intuition and Expertise in the Era of Computer*" about how humans are able to form a spontaneous perception, yet having a foundation of experiences. The scientific definition of this state is called *intuition*. [6]

The article pictures five different stages of skill: novice, advanced beginner, competent, proficient and expert. This evolution of skills says that one begins as a novice, which implies with the need of an analytical decision making process. It ends with reaching an expert level of skill that will translate the collected experience into the ability of an intuition based decision making. The experts' way of decision making does not need to reason nor undergo evaluations. It has the characteristics of being spontaneous and act on already possessed knowledge.

Engineers are educated to make carefully considered decisions based on facts, time and money. Real life projects often lack the time needed for these thoroughly evaluated decisions and are therefore needed to be intuition based instead. [6] [7, pp. 62-63]

3 Method

This chapter will describe and motivate the selection of methods that were used during this thesis. The chapter begins with an explanation of how the methods answers to the research questions. The methods will then be explained in a general point of view to give the user the knowledge needed to ease the understanding of the implementation chapter.

3.1 Connection between research question and method

To answer this thesis's research question, the following methods from the applied design process are presented.

The theory behind benchmarking is presented since it gave tools on how to gain a general understanding of the available bike carriers on the market. The theory of a user study provided knowledge about how it could be possible to gain understanding about the interaction between the user and the product. The 6-3-5 Brain writing method enabled development of different concepts. These gave solutions to how the questions could be answered. Knowledge about how to eliminate and then select concepts, were gathered from the theory of PUGH. To aid the concept elimination was the theory of Quality function deployment used. This enabled weighting of the demands in the specification that were used in the PUGH's matrix. Finally, a method to ensure and confirm the validity and reliability in this thesis was presented. This will answer to the research question since the validity and reliability will state if the used design process is suitable or not.

3.2 Concept study

To be able to answer the research questions, this study was structured as a concept study. Concept studies could be applied on many different projects, but mainly used during redesign or improvements of existing products. This kind of study intends to systematically structure and document the creative work of product development, and provide good traceability throughout the work. [2, p. 115]

The practical approach of a concept study follows certain steps during the process. The design process are mostly generic, but have to be adjusted in accordance with the unique context of the company or the project. Depending on the extent of the project, certain steps could be excluded to optimize the process for that certain project. [8, p. 18]

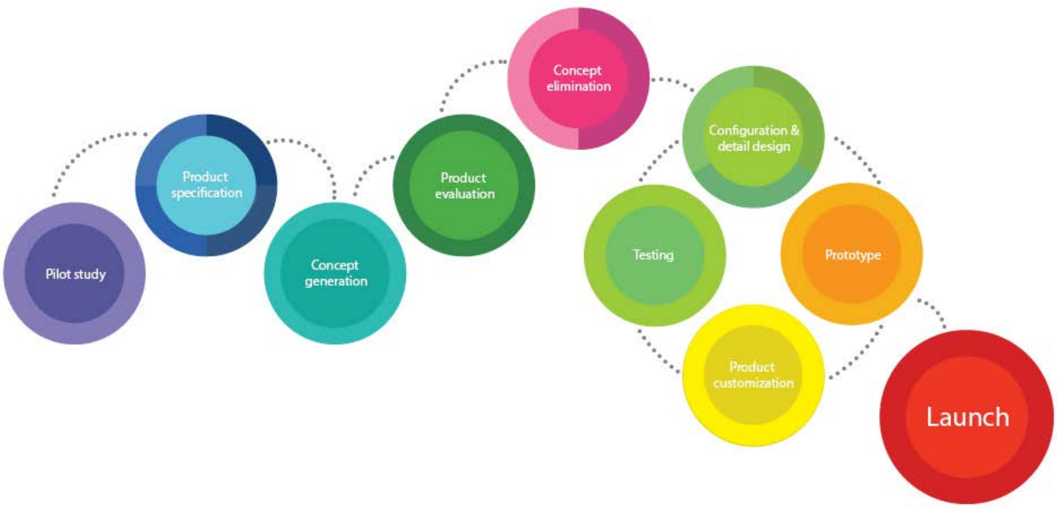


Figure 3 shows the design process followed in this thesis.

3.3 Pilot study

3.3.1 Benchmarking

Benchmarking is a method that is used to study the competitors on the market. The study can be applied to several of the different steps in the product development process. When developing new products, it should be of great interest for the company to study the competitors' products. In focus should those with similar functions be. Both the already existing products but also potential launchings should also be taken into account. To identify the competitors' strength and weaknesses can be of great help for the company and might expose new opportunities. [9, pp. 67-68]

A benchmarking could reveal concepts already answering to the same, or similar, problem as the one wanted to be solved. This would give helpful insights in what strengths to aim for and weaknesses to avoid. [8, p. 127]. Information about competitors' products can be gathered via market research or by performing product tests. This information can help to fully understand the possible advantages that these have. This kind of information are often gathered in a cross-reference table, which enables an overview for a simplified analysis. By continuously keeping a benchmarking process going, experience and understanding for the certain market could be attained. This could help to identify major new product trends which can be considered essential to sustain a relevance in the market and the consumers' approval in today's short product lifecycles. [9, pp. 67-68]

3.3.2 User study

3.3.2.1 *Video Ethnography*

Video ethnography is a method that can be used as a user study. This is used when behavioral patterns and insights can be withdrawn from an analysis of a video capture. The objective is to capture people's interaction with a product or perhaps the behavior in a certain situation. By using video recording, the researcher has the ability to capture both visuals and audio recording over entire periods of time. This is useful since the data can be examined unrestricted amount of times which can lead to revelations that passed unnoticed during the implementation of the experiment. The first thing to consider when performing a video ethnography is to determine what to film. The goal of the study should reflect on how the experiment is conducted, whether it is an interview, a recording of environmental changes, levels of activity or an interaction with a product. To be able to use the data obtained from a user study like this, it is required that the user sign a permission and release form. This enables the researcher to film and use the footage of the participants performing the experiment. When shooting the video, the participants should be informed of what is wanted by them and how the experiment is performed. The analysis of the footage should be done in small portions at a time, either together with the participants or the other members of the team. This can be a time-consuming process and a general rule is to allow three hours of analysis for every hour of footage. When processing the information later in the design process a log created during the analysis can be a useful reference tool. [10, p. 109]

3.3.2.2 *Ethnographic Interview*

Ethnographic interview is a method that can be used to document peoples' activities and experience from their perspective. It is beneficial to perform the interview in connection to the activity, since it often aids the participants' memory and allow them to demonstrate the activity. This method enables the researcher to learn about the participants throughout both their words and actions.

It is of importance to thoroughly plan the interview before performing it. The plan should include who will participate, how it will be performed and the intention behind the interview. The activity is ought to be documented to enable the researcher to reflect over the results afterwards. After the interview the researcher should analyze and draw conclusions of the activity as soon as possible. This is to keep a fresh memory of it. [10, p. 111]

3.4 Concept Generation

The method for concept generation comes from the category of *creative methods*, mentioned in [2.2.3].

3.4.1 6-3-5 Brain writing Method

The 6-3-5 brain writing method is versatile and a commonly used method in product development contexts. The technique is easy to conduct since it does not need a lot of instructions or equipment. The group of people participating in the session needs to be well informed regarding what the problem consists of and what the goal to achieve is. The number of participants can vary some but in general this brain writing method works best with six or close to six people. It is of high value making sure these people feel wanted and that their special talents are needed.

The method has got its name, 6-3-5, from the way it is conducted. There are **six** participants, all producing **three** solutions each. This is done individually by putting down the concepts in the shape of sketches and associated explanations on three separate papers. After a few minutes (e.g. 5 minutes) the participants are told to forward their solutions to the person next to them. After the change, the task is to follow up and further develop the solutions one was given. This is repeated until all original solutions have been followed up by all participants. Which in the case of six participants results in **five** repeats, thereby the name 6-3-5.

With the help of this method the solutions obtained is influenced by multiple angles of incidences, where the participants use each other's ideas to springboard their own. This gives a wide result of solutions in a short amount of time, making it an efficient and useful method. [2, pp. 170-171]

3.4.2 Quality Function Deployment (QFD)

When developing new products, it is essential to understand and create suitable engineering specifications. These will come to set the standard for how well the product will meet the customer requirements. There are many techniques available to use when generating the engineering specifications, however, the currently most popular one is called quality function deployment (QFD). Using the QFD method will facilitate the understanding of the problem and it will help gather necessary information in the pilot study during the design process.

The *house of quality* is the physical appearance of the QFD method and is also known as the QFD diagram. This is a house-shaped diagram consisting of nine different sections, also called the rooms. [7, pp. 141-150]

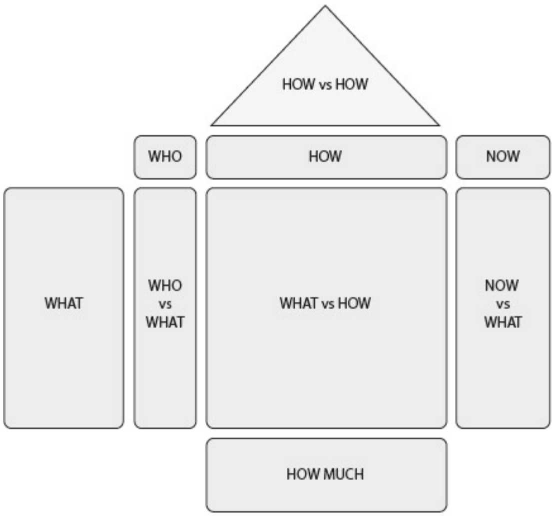


Figure 4 shows the QFD diagram

Who - The first step in the process to complete the QFD is to identify the customers. The customers are often the consumers but it is important to remember that some products are not consumer products. To make sure all customers are included and have been identified, one method to use is to visualize the product's entire life cycle. Starting with the original problem and where the idea was created, then ending with dismantling and recycling. Analyzing every step of the way and acknowledge the different stakeholders. [7, p. 151]

What - Next step is to identify *what* the customers want the product to do. To whom the "what" is important to should also be identified - *who vs what*. Considered there are stakeholders such as; consumers, production customers and marketing customers, the "what" must include them all. Usually, the consumers want a product that works well, looks attractive, has a long lifetime, is easy to maintain and has many features. While the production customer is more interested in how easy the product is to manufacture, if it can be produced by existing facilities and whether or not it uses standard parts and methods. Finally, the marketing customers wants the product to be easy to store, package and transport as well as being attractive and suitable for display. [7, pp. 151-156]

Who vs What - The *who vs what* room is dedicated to state the importance and weight of the requirements. One way to do this is to instruct the customers to rate the requirements from one to ten. Letting one be the least important and ten the most. This however, often gives an insufficient result because it is normal that *all* the requirements score a high value such as eight, nine or ten. This is because most of the requirements often are considered to be important. A solution to this is to let the customers rate the requirements with a total sum of 100. Giving the most important requirement the highest score and so on. [7, pp. 157-158]

Now & Now vs What - Answering the "*now*" is done by studying existing products. Awareness of what already is available on the market is essential in developing a successful product. This process can be direct compared to a competition benchmarking [3.3.1] and will reveal the opportunities there are to enhance and improve the existing products. [7, pp. 158-160]

How - To measure how well the customers' requirements are met, engineering specifications need to be developed. These originate from the requirements but are stated in terms of parameters that can be measured. Having a specification saying that the car door should be able to close easily, is not enough since easily can be interpreted differently among users. In this case, easily has to be translated to a targeted value such as e.g. "The closing force of the car door should not exceed 20N". [7, pp. 160-165]

What vs How - The strength of the relationship between the engineering specification and customer's requirement are measured in the "*What vs How*" room. The ratings are 0 = no relationship, 1 = weak relationship, 3 = medium relationship or 9 = high relationship. Every requirement should have at least one strong relationship with a specification. Ideally one specification should have a relationship with more than just one requirement. [7, p. 166]

How much - In the example of the closing car door, 20N is the targeted force. In this section, all the targets are set and presented as well as their importance to be met. This leads to evaluation how much effort it will expend to reach a target. [7, pp. 166-169]

How vs How - This section exists to easier realize if and how there are dependencies between the different engineering specifications. When trying to meet one specification, others might get affected in either a positive or negative way. The specifications are shown in a diagram with diagonal lines connecting them together. If, during the progress, one specification is noted to depend or affect another it is shown by rating a "+" if the dependence has a positive effect. The same way a negative effect is shown with a "-". "++" or "--" can be used to show strong dependencies. The ideal result to achieve is independence among all specifications. If too many specifications depend on another, they should be revisited. [7, pp. 169-171]

3.5 Concept elimination

3.5.1 PUGH

A decision-matrix called Pugh's matrix can be used when comparing different concepts. The method was invented by Professor Stuart Pugh of the United Kingdom. He saw an opportunity to elaborate the second room in the house of quality, from the QFD [Figure 4]. From there the Pugh's method was invented [11, p. 61]. The method offers the user the ability to compare different concepts to each other and evaluate their ability to meet the determined criteria. The scores can be summarized and provide a result that points out the strongest alternatives.

The matrix can have different layouts depending on what is compared, who is doing the comparison and what you want the process to answer. A general matrix can be divided into five sections and completed in five steps.

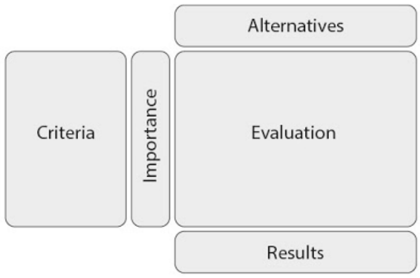


Figure 5 shows how a PUGH-matrix could be structured

Alternatives - In this section the different concepts or alternatives are stated. It is important that the concepts have gone through the same amount of work and are at the same progress level. Sketches of the different concepts can be a good way to quickly remember and compare them relative to each other. There is always one concept used as a datum. This can either be an already existing product, abstracted to the same level as the other concepts, or an earlier concept estimated to be the strongest alternative. The datum is usually positioned in the first column of the section.

Criteria - To ensure that the product meets the customer's requirements, engineering specifications are created. These should be able to be answered objectively and are often taken from the requirement specification. Consumer price, general packing, cost or feasibility are some examples.

Importance - To make sure that the result take into account, the different importance of the criteria have to be weighted. This is usually done in the quality function deployment (QFD) [3.3.3] where the relative importance of the requirements are determined. The importance is given as a multiplication factor.

Evaluation - When completing the evaluation, the datum is used to compare all the concepts against the criteria. Each comparison is judged to be better, worse or same as the datum. The results get presented by writing "+1" as better than, "-1" as worse than or "S" as same as. A concept that scores better than the datum on the first criteria will get credited +1. If the criterion has an importance of 5 the result for that concept will be 5, (5×1). If the same concept gets evaluated lower than the datum on the second criteria, that has an importance of 3, the result is 2, $(5 \times 1 + (3 \times -1))$. This is done with all the concepts and criteria until a final score can be summarized.

Results - If a concept gets a score higher than zero this concept will, in general, meet the requirements on a higher level of accuracy than the datum. Which as a conclusion means that this solution is a better alternative. If more than one concept gets a positive result it can be necessary to do further comparisons, making the decision taking possible. [7, pp. 240-243, 157]

3.6 Validity and Reliability

To guarantee quality in any research, it is of importance to evaluate the validity and reliability. High validity ensures a *quality research*. This proves that the right phenomenon have been studied during the design process. The validity can be strengthen with known and accepted theories, good measuring equipment and accurate measurements. To perform a *quality study* with good reliability, is rather about discovering the uniqueness that occurs with different situations and the relation to the background, than achieving a correct result. [12, pp. 105-106]

Olesen provides five factors in his article "*Concurrent development in manufacturing based on dispositional mechanisms*" [13] that can be of use in order to describe validity and reliability in a quality research:

- *Internal logic* – known and accepted theories are the basis of the research, and the work is stringent from the problem to the result.
- *Truth* – the theoretical and practical result can be used to explain real phenomena.
- *Acceptance* – the research is accepted by the research community. The tools introduced are accepted by practitioners.
- *Applicability* – the use of the introduced tools leads to enhancements over the situation if they had not been used.
- *Novelty value* - *new* solutions are presented or new ways of looking at a problem are introduced.

4 Implementation and Result

This chapter will present what the study resulted in and what implementation that lead into those results.

This concept study began with a pilot study. Here, the intention was to define the demands from a both technical and user perspective point of view. A benchmarking, research gathering, user study and an interview were conducted in order to achieve conclusions from the pilot study. The gathered information was transformed into a product specification to state the demands of the product. Followed by a brain writing process which generated different concepts. The concepts later got evaluated and eliminated thereafter. The finalization of the selected concepts got developed in an iterative process.

During the development of the final concepts, the process described in the theoretical background with its associated methods are performed continuously [Produktutveckling - Effektiva metoder för konstruktion och design].

4.1 Pilot study

To be able to gather information and knowledge about both bicycles and carriers, a pilot study had to be performed. This study consisted mostly of information research done on the internet. Getting familiar with all the terms and learning more about racing bicycles in general as well as gather information regarding design differences.

4.1.1 Project planning

In the early stages of this thesis, the project was planned and organized in a Gantt schedule. This to gain understanding of the scope and time needed in every moment of the project. The schedule can be viewed in the attachment chapter [Attachment 1, GANTT].

4.1.2 Benchmarking

The completion of the benchmarking began with the creation of the benchmarking diagram, found in the attachment chapter [Attachment 2, Benchmarking]. This consisted of nineteen features, design solutions or limitations that were to be compared between eleven different roof mount bike carriers that had been appointed to be the most similar to the Thule Sprint XT. The answers was found by, via the manufacturer's webpage, reading about the carriers and the information that was provided about them.

4.1.3 User study & Interview

To be able to collect information regarding how the interaction with the existing Thule Sprint XT looked like, a user study was conducted. To be able to replicate as realistic a scenario as possible, without the access to a car, the carrier was mounted to a circular saw rig. The rig had a similar t-track [Attachment 3, Picture of Thule t-track system] as Thule’s car racks have. This made possible for a stable set up. The rig then was secured to a height adjustable table that made it possible to easily change the height to mimic different car heights.

The users executed the mounting of the bike with no other external assistance. This was to ensure that their interpretations and behavior was not affected by others and therefore making sure for an intuitive experience. The environment was made to be as neutral as possible.

The problem the user was told to solve was to mount the bike to the carrier in a way they thought was the correct way and so that they felt comfortable with how it was being secured. The user got no further explanation or manual of how to use the carrier. This was to examine how well the understanding of the product was mediated to the user. In this way, possible improvement opportunities of the product’s intuitive use could easily be noticed. If, however, the user did not know how to interact with the carrier and could not figure out how to mount the bike, help was given.

The experiment was video recorded with the help of a smartphone camera which was mounted to a stand for a stable and consistent shot. The footage then got analyzed and an edited video was created. In total six people got studied and since one did not want to get recorded, video footage of five users was collected.

Figure 6 shows a picture from the user study

Figure 7 shows a picture from the user study

After analyzing the video footage several recurrent problems were noticed. The most obvious one regarded the knob in the front of the carrier, whose function is to tighten the *sprints* [Figure 32 shows the parts of the scissor system] and thereby securing the bike. It was by many users only assumed as a cover with no intended purpose. If it were to be turned, none of the users completed the tightening fully by turning until the feedback click sounded. The click comes from the internal torque limiter which disengages the mechanism making it impossible to further tighten the sprints. As this being one of the key features that Thule Sprint XT offers and makes it stand out among its competitors, this result strongly suggest that improvements should be done. Furthermore, the general understanding of the carrier and how to use it has in this user study shown to be difficult for first time users without instructions. This suggests that the product is lacking in intuition [2.5]. The result strengthens this assumption since even on the second attempt not all users mounted the bike correctly.

Once a user was introduced to the experiment, they were asked a few questions regarding their previous knowledge of race bikes and their physical appearance, education and gender. This could later be helpful when studying the results since certain exceptional cases of results could be related to a certain starting point. When the experiment was over, questions about the mounting and usage of the product were asked.

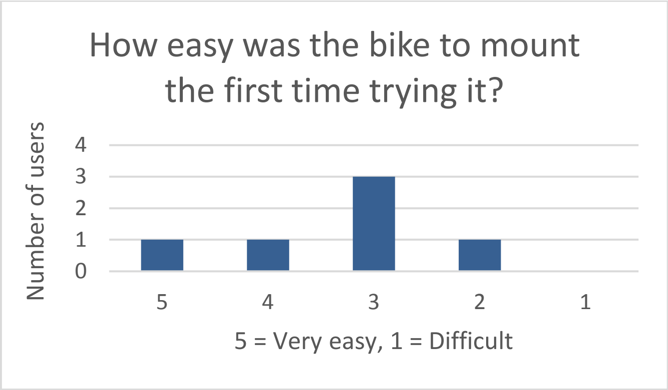


Figure 8 shows a graph over answers from the interview. The majority found that the difficulty level of the mounting of bike onto bike carrier was from medium too easy.

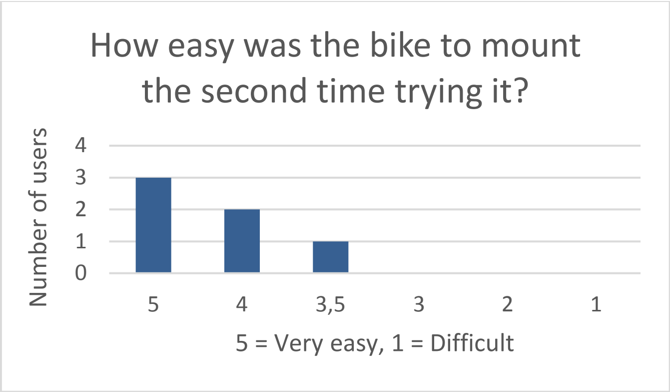


Figure 9 shows a graph over answers from the interview. All the participant found it easier to mount the bike the second time trying it.

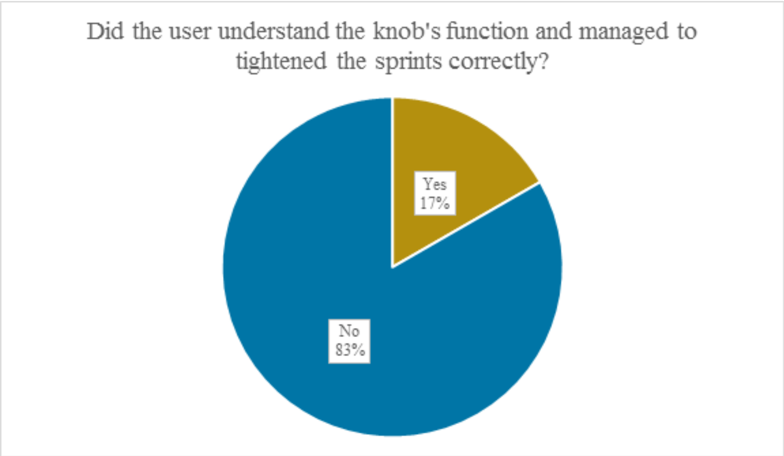


Figure 10 shows a graph over answers from the interview about the understanding of the knob's function

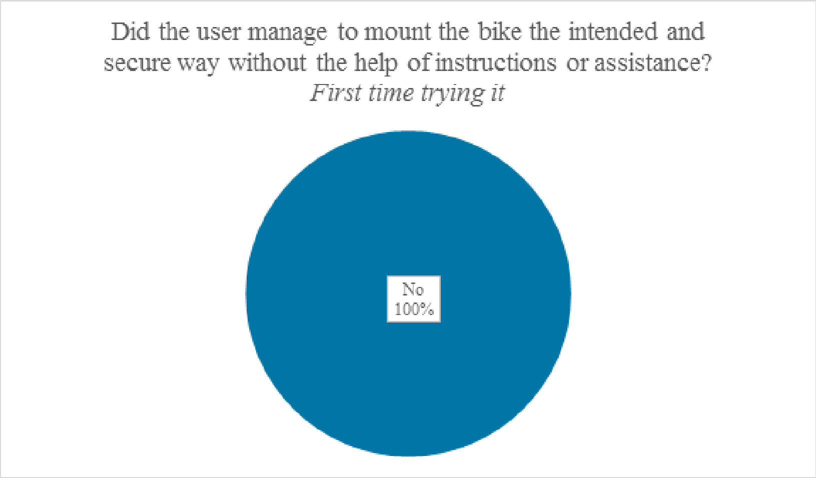


Figure 11 shows a graph over answers from the interview. No one from the user study was able to mount the bike without any instructions.

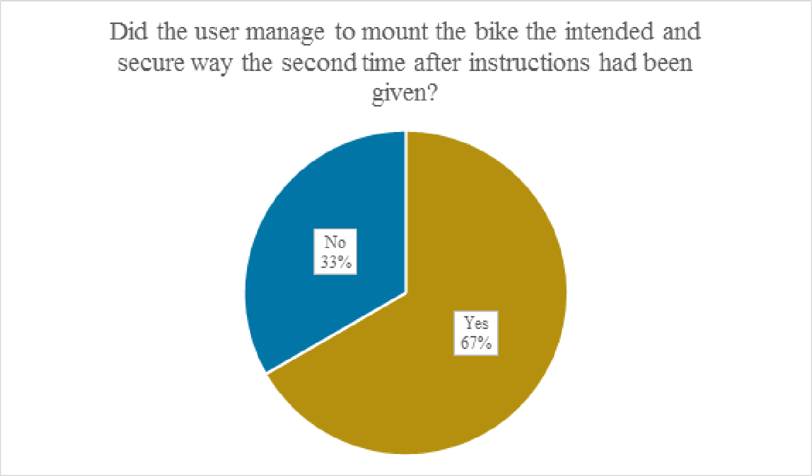


Figure 12 shows a graph over answers from the interview. The majority of participant managed to mount the bike in a secure way the second time.

4.1.4 Quality function deployment (QFD)

The part of the quality function deployment that were of interest for the development of the new Thule Sprint XT was the weighting factor points which later were used in the PUGH's matrix. The weighting factor points were established by completing the Technical product study matrix [Attachment 7, QFD] produced by Thule. This matrix is equivalent to the "*Who vs What*" section of the QFD [3.3.3]. However the method used here differs from how David G. Ullman explains the process. The method Thule has developed to produce the weight factors is by comparing the requirements against each other. By composing a matrix where the requirements are stated in both the rows and columns, a diagonal comparison where they one by one gets weighed against each other can be done. The input answers only to which of the two, at the time compared, have a higher importance than the other and scores 1 respectively 0. If two requirements are rated the same importance they both score 0,5. The result will give all the requirements a weighting factor between zero and the number of requirements used, which in this case were 20. The highest factor reached were 18,5 and the two requirements achieving this were "*equally distributed force over the sprints*" and "*withstand rough handling*". Several requirements had a factor of 17 or higher and the similarity between these were that they contained demands that were set to be reached and not wished to be fulfilled, such as "*fit bikes with disk brakes*" and "*ability to handle carbon fiber frames*".

4.2 Requirement specification

The information from the pilot study together with the requirements resulted in a specification and can be found in the attachment chapter [Attachment 6, Requirement specification]. Since the project was assigned by Thule, some demands were already set by them. Some of the demands, set in the pilot study, were later excluded since they were judged to no longer be relevant to this thesis. They were however, rather important when stages further on in the process were reached. These were demands such as accomplishing the "*city car crash test*".

4.3 Concept generation

4.3.1 Session 1

The first concept generation session was conducted in the early stages of the developing process to gather as much external input as possible. The group were handpicked out of students of the technical university of Jönköping, to make sure for a meeting where desired experience and knowledge were present.

When all participants were gathered, the information were introduced to them and a warm up exercise handed out. This was an exercise to activate the creativity and imagination and lasted five minutes. When the five minutes had passed everyone explained what they had drawn to let the others be inspired by their possible different approach.

The focus of this session was to bring out concepts regarding the mounting of the front fork to the carrier. The previous solution, which Thule Sprint XT consist of, features a construction were two sprints are tightened to clamp the drop out areas [Attachment 11, front fork] fastened. The goal was to find new solutions solving the same problem. The participants got instructions to set aside economical and manufacturing limitations. This could increase the imagination and flow of generating solutions.

After this, plain white papers and a few post it notes were handed out. The white paper were used by the participants to sketch and/or write their concept/s. After the four minutes had passed, which this part were set to take, the papers were passed to the person next to. The goal now was, with help of the post it notes, to add on ideas to the original concept. This part was also set to last for four minutes. This was repeated until the original concept, now with at least six additional ideas, ended up at where it originated from. The final step of this concept generation session was to have a common brainstorming where all concepts were freely spoken about and inputs from all participants were welcome.

Figure 13 shows a picture from the first session

4.3.2 Session 2

The second concept generation session was decided to have a different orientation than the first one. In focus was to find a solution on how the mechanism of the tightening feature could be constructed. With this being a rather difficult goal to achieve, it was necessary to have clearly specified limitations to the problem. The participants who got invited were informed in advance about the session's goal and what the limitations were. In this way more solutions and concepts could be produced since the problem was narrowed down to one specific thing and therefore not being too big to grasp. The participants were told to try and come up with a solution to how the tightening mechanism could be designed, still using the same design for the sprints and with an input force [Input] of any kind. This meant that the rotation knob could be changed out for e.g. a lever, a skewer or a button. Which in turn could lead to a linear force instead of a rotating one. To give the participants further knowledge they were sent a video of how a bicycle is fastened to the current Thule Sprint XT as well as a picture [Figure 14] explaining the feature. During the session the method and technique used were the same as in the earlier concept generation session [4.3.1].

Figure 14 shows a description of the function of Thule Sprint XT

4.4 Concept

4.4.1 Concept 1

This concept uses the flexibility of the wire. The axial force needed to tighten the sprints acting in one direction can with the help of wire easily be redirected. This makes for a solution enabling the possibility to eliminate a rotational input and instead have a linear one. One of such could be some sort of lever or arm that with the use of a folding motion pulls the wires resulting in the sprints being tightened. The part in which the wires are fastened to can rotate around its central point which allows for deviations in the fork bones and thereby not risk damaging it.

Figure 15 shows concept 1

4.4.2 Concept 2

This concept uses a specific component to solve the mechanical problem. In this solution, in contrast to the other concepts, the system has its natural state in the tightened position. When the input force is added, the system will open and enabling the mounting of the bike. The input force will separate the sprints. Since the construction continuously aims at attaining the normal state, the tension will maintain and thereby fix the fork. Due to conceivable deviations of the fork bones it is vital to equally distribute the force between the sprints. This is solved by the characteristic of the component.

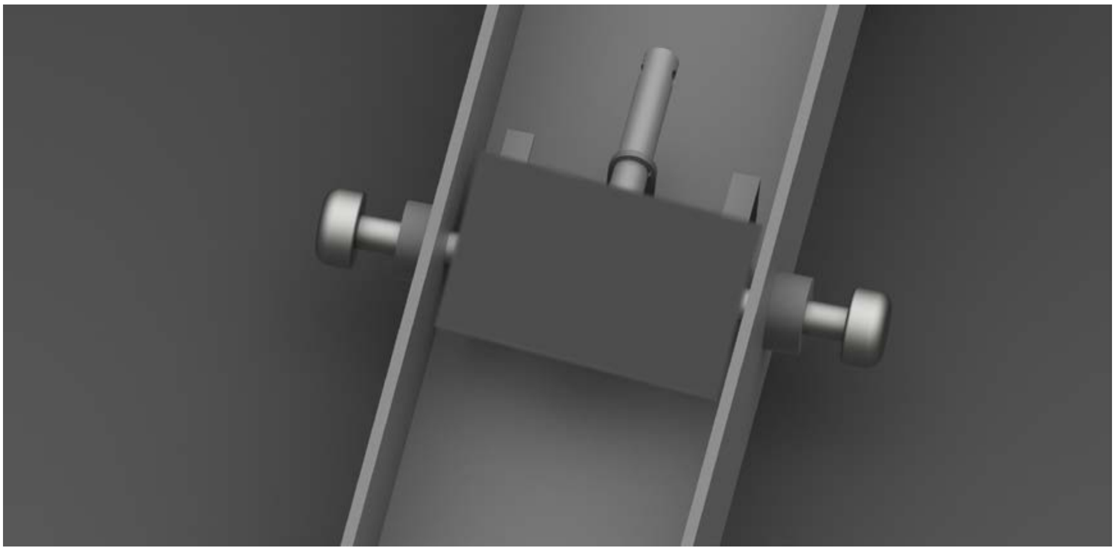


Figure 16 shows concept 2

4.4.3 Concept 3

The principle behind this concept is conversion from rotational force to axial force. Since the axle is threaded in both directions with the center as changing point, rotation of it will result in distance change between the both threaded links. Much like the well-known jack screw that is used to lift cars. If the distance increases, the system is tightening, pulling the sprints in. By letting the axle have room to slightly move, the force is able to compensate for deviations of the fork bones and be equally distributed on both sides.

Figure 17 shows concept 3

4.4.4 Concept 4

The principle behind this concept is to redirect the motion from the input force with the use of rails. This is done by letting the sprints be attached to the rail. When the input force moves the rail forwards, the sprints will be tightened. The angle of the rail is determined by the length of the springs. These will, during tightening, get pressed together which will enable the adjustment of the tightening force. This concept uses rigid springs to allow the rail to slightly move and thus compensate for derivations of the fork.

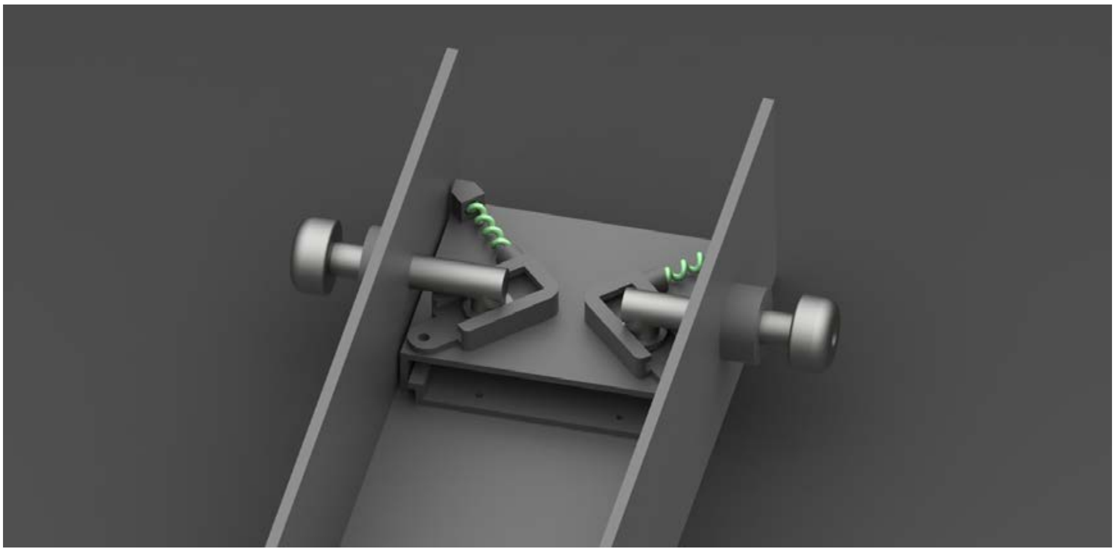


Figure 18 shows concept 4

4.4.5 Concept 5

This concept uses a combination of wire and lever to transfer the input force into the direction of the sprints. The input force is applied via a wire. The wire connects with a lever that has an axle to create a pivot point that will transfer the input force into the tightening force of the sprints. The part in which the wires are fastened to can rotate around its central point which allows for deviations in the fork bones and thereby not risk damaging it.

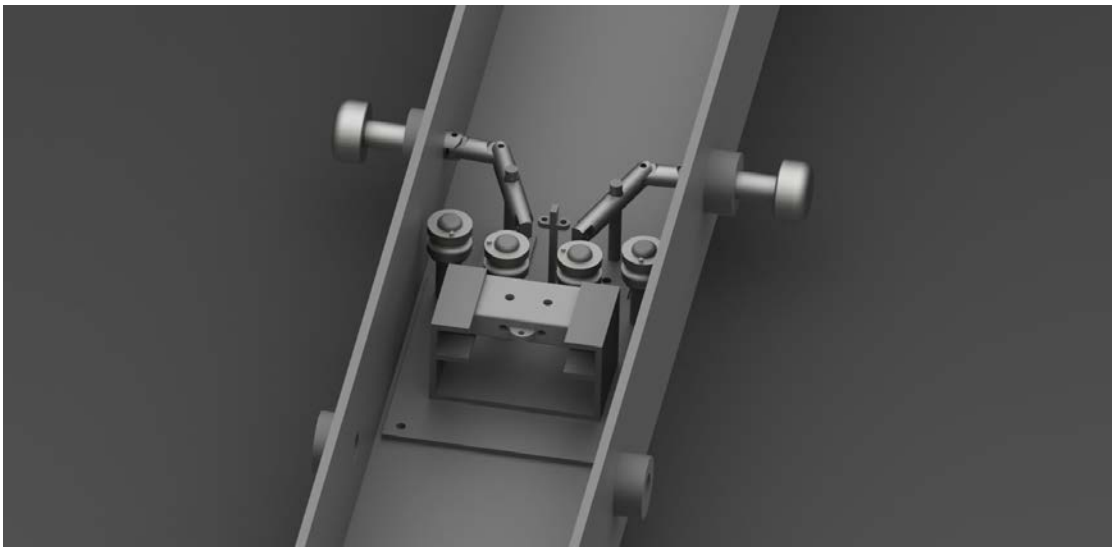


Figure 19 shows concept 5

4.5 Concept elimination

4.5.1 PUGH

The concept elimination process, were the five generated concepts got narrowed down to only two, was performed with help from a PUGH matrix [Attachment 9, PUGH]. The matrix used was produced by Thule, and is customized to fit their developing process and products.

The engineering specifications, listed in the "*criteria section*" [3.6.1], were taken from the requirement specification [Attachment 6, Requirement specification]. The concepts got compared to the datum answering to these specifications one at a time. The datum used was the Thule Sprint XT carrier. The comparison worked out by giving score to the five concepts in regards to their solution and if the demand was improved, worse or the same as the datum.

The result ended in advantage for concept 3 with a score of 101. Since an outcome of a PUGH matrix should be considered as guide lines, the two concepts with highest score were selected. Therefor concept 2 also were considered to be included in the further development, since it scored 100.

4.6 Configuration and Detail Design

4.6.1 Testing of the tightening force

To be able to get determine the tightening force needed for a secure mounting of the bike, tests were conducted. The test equipment consisted of a measuring cell and the quick release skewer of a front wheel. The measuring cell is an instrument used to collect data regarding pressure. When connected to a display, wanted unit and scale can be selected. The output were in these tests given in Newton and measuring the tightening force. The tests were performed by letting people tighten the quick release the same amount they would tighten a wheel to the front fork of a bike. They were asked to stop when they thought they had reached a secure level. The results showed a wide range from between 600 – 6500 N. This test also gave perception regarding what dimension a potential lever would need to enable enough force to be applied.

These tests, together with the observations received from the pulling test [Attachment 10, slippage test], resulted in the determination of the tightening force interval. This was set as a requirement letting the interval reach from 600N-3600N. A tightening force of 600N was the lowest limit of which the bike was fasten securely. The upper limit of 3600N was set as the maximum force a carbon fiber frame could handle without breakage.

Participant:	1	2	3	4	5	6	7
Force (N):	3800	1300	4400	2700	4980	748	6507

Table 1 shows the magnitude of force every participant applied into the system.

Maximum:	6507 N
Minimum:	748 N
Mean value:	3490,7 N

Table 2 shows the maximum, minimum and mean value of the force applied into the system.

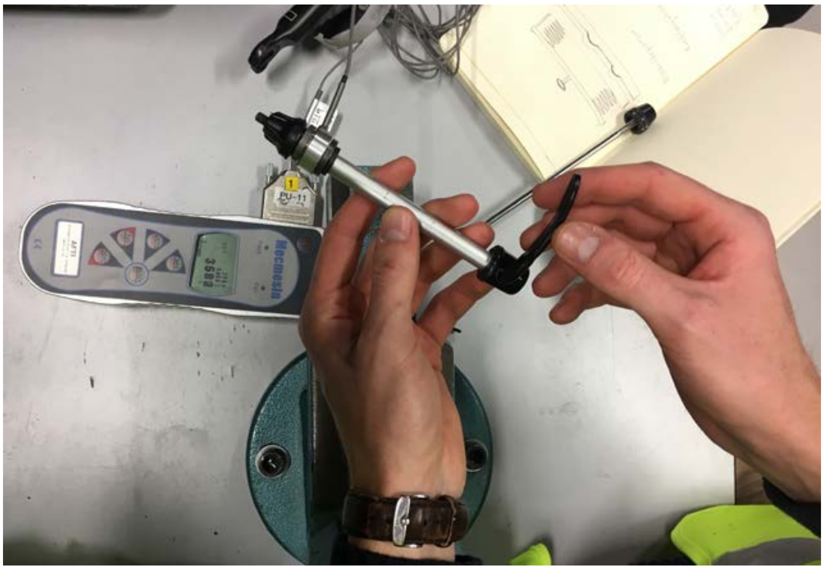


Figure 20 shows a picture of the test equipment

4.6.2 Testing prototype

The principle behind concept 2 was dependent of a special component's characteristics. This concept and the construction of its mechanism with the special component needed to be tested to verify its feasibility. The testing also had the intention to reveal if the component would be able to fit inside the construction of a bike carrier or not.

This test required special equipment to be able to give accurate results. These were created in Thule's prototype workshop with some help of prototype technicians. The created equipment included one metal axle that represent the front wheel quick release. This part had to go through development and two more versions of it were later produced. Washers that would distributed the input force equally on the measuring cell to achieve accurate results also had to be included in the set up. Special washer with engraved ribs [4.6.4], got machined to represent the sprints and faced the drop out area of the fork.

To be able to measure the amount of force applied during the test, a measuring cell was used once again.

Figure 21 shows pictures of the first created test equipment. Version 1

Figure 22 shows pictures of the second created test equipment. The axle had to be imporved to ensure an accurate result. Version 2

Figure 23 shows pictures of the final created test equipment. This meant a better dimensioned axle, washers with engraved grooves and special made spacers. Version 3

Figure 24 shows a picture of the test, which engineers from Thule checked.

The results from the tests gave a realization that it was possible to develop concept 2 and still meet the demands from the specification. Necessary knowledge about the needed component were gained and since the results were positive, Thule decided to start a patent process research.

4.6.3 Input

The work the user put into the system for opening and closing of the carrier is called the input force. As the concept generation process began, the limitation to how this input force would take form was unrestricted. The former rotating knob did not need to be recurrent in the new concept. Solutions such as a hand lever, an electrical motorized system or hydraulic were imagined to broaden the mindset. However, the solution of how the user could input the force into the system depended on what mechanism was used. This meant that the design solution for the input force had to be done after the mechanism was decided. After having the scissor jack concept scoring the highest value from the Pugh's matrix it was clear that a rotational input was needed. A few of the input force concepts were eliminated straight away with the reason of being too costly. Such as the electrical motorized ones as well as the hydraulic based ones. Having a hand lever produce a rotation torque is possible by the use of gears and interconnecting parts. The simplicity and cost efficiency of a knob were in this context however evaluated much higher.

Figure 25 shows the difference of the knob's design

4.6.4 Sprints

The concepts generated during the first concept generation session were all put aside. This was due to them all consisted of design solutions were the sprints had been removed. They had instead other solutions for how the fork could attach. Since the sprints are similar to the way the quick release of the bike wheel fastens, they are considered to be the overall best solution. In this way, the tightening pressure acts on the same areas of the *drop outs* as the quick release, which is what the bike is built to withstand and therefore most suitable.

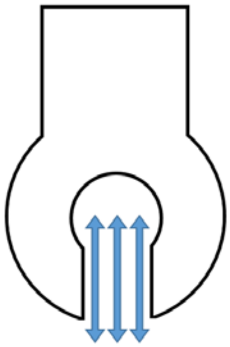


Figure 26 shows the drop out of the front fork, with arrows resembling the slippage direction

The design of the sprints are limited since the area on where it will come in contact with the fork do not vary much. Tests were conducted regarding how different ribs or design of the sprint's head could impact how securely the bike attaches to the carrier. During concept testing [Attachment 10, slippage test] slippage were noticed when flat heads and a tightening force lower than 600 newton were used. Four different design concepts of the sprints got developed; *horizontal, circular, centric* and *lock-washer* to determine what solution offered best grip between the sprints and the fork. With respect to which resources were available, these designs could not be manufactured and the results come from analyses of the design.

4.6.4.1 *Horizontal*

Offers best grip when slippage acts in horizontal or vertical direction, determined by the alignment of the ribs. When aligned horizontally, highest friction will be given when slippage occurs vertically.

Slippage direction:

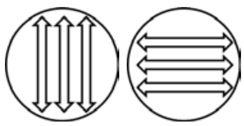


Figure 27 shows the sprint with horizontal ribs

4.6.4.2 *Circular*

Offers best grip when slippage can occur outwards.

Slippage direction:

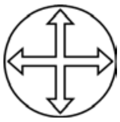


Figure 28 shows the sprint with circular ribs

4.6.4.3 *Centric*

Offers best grip when slippage in rotation in both direction occurs.

Slippage direction:

Figure 29 shows the sprints with centric ribs

4.6.4.4 *Lock-washer*

Offers best grip when rotational slippage in one direction occurs. This direction is when the rotation faces the flat sides of the incline.

Slippage direction:

Figure 30 shows the sprints with lock-washer ribs

4.6.4.5 *Sprint design*

Due to the design of the drop outs the front fork will be fixed horizontally and slippage will only occur vertically. The best choice for the design of the sprints are therefore the horizontally aligned ribs. Because of the sprints being fastened to *link3a* and *link3b* [Figure 32 shows the parts of the scissor system] the rib alignment will stay in a horizontal position making sure for best possible grip.

4.7 Final concepts

After joint discussion with the project participants from Thule Group, concept 2 got selected as the more interesting and promising one. This concept had a solution to the problem not before thought of by Thule. Because of this, they expressed great interest in it. This was also the reason why details regarding this concept cannot be described or shown in this thesis. Thule Group took action in the patent investigation of the solution and therefore this concept was confidential. Concept 3 was also considered interesting and will as well be presented in this chapter. However, further development, testing and concept finalization were from this point and onwards mainly focused on concept 2. Since this information also was confidential, the following results will include both concept 2 and 3, but concept 2's results will be censored.

4.7.1 Concept 2

This concept consists of a solution that utilizes that the value of the applied tightening force has an interval. That interval range from 600 to 3600 N [Attachment 7, Requirement specification]. This interval was stated such that with a force of 600 N, the bike's fork bones will be tightened to the carrier with just enough force for a firm and sufficient grip. Having a limit of 3600 N makes sure that frames of carbon fiber will not get damaged. The interval allows for solutions where a certain predetermined tightening force was not a must. This in turn leads to the possibility of eliminating the need of a torque limiter. This was something that concept 2 takes advantages of. The solution offered in concept 2 was simple yet manages to meet all requirements and are at the same time calculated to have a lower production cost than the Thule Sprint XT.

By the usage of the *special mechanical component*, this concept interacts with the user in only two positions. Either the system is open or closed. The operation of tightening the system, applying the force, have been simplified by doing this. This enhances the user interface and makes for improvements regarding the product's ability to mediate its usage [Intuition]. When the system is open, the distance the sprints extend are 10 millimeters which lets a fork with 8 millimeters of fork bone thickness attach to the carrier with ease. To tighten the sprint the user needs to engage with the input giver, which in concept 2 can have the form of either a knob or a lever, both solutions were proposed to Thule. Then by turning the knob or lowering the lever, the system will close and a force between 600 and 3600 N will react via the sprints on the both fork bones, securing the bike to the carrier.

4.7.2 Concept 3

Figure 31 shows a render of concept 3

Concept 3 was originally inspired by the commonly known scissor jack. This is a product used to partially lift a vehicle or other object off the ground by utilizing the mechanical properties of threads and scissor design. The idea of making use of scissor design as part of the mechanical solution was considered by Thule as a good concept.

The prototype of this concept was created from seven larger parts:

4.7.2.1 *Housing1*

Figure 32 shows housing1

This part was the biggest piece in the assembly of the concept. It holds all the internal components as well as being equipped with the mounting structures for the rail and the front rack mount base. It has two cut outs which makes room for the caliper mount [Attachment 11, front fork].

Housing2 mounts to *Housing1* by the two screws that fits to the *mountrig1*. The upward facing side connects by the *clip-on* latching onto *latchcutout*. By having *housing2* being detachable from *housing1* the assembly of the prototype was made possible. This creates the space needed to install all the components of the *scissor system*.

4.7.2.2 *Housing2*

Figure 33 shows housing2

The *indication* for the closing and opening rotation direction are placed on *housing2* for a suitable placement to attract the user's attention. The *clip-on* is a snap fitting to facilitate the mounting of *houising2* to *housing1*. This makes it easy to assemble and disassemble if needed.

4.7.2.3 *Rail (with associated rear wheel strap and rear rack mount)*

Figure 34 shows the rail

To be able to present the prototype in its proper context and with the ability to mount an actual bike, the rail from Thule Sprint XT was used to mount the prototype on.

4.7.2.4 *Front rack mount base*

Figure 35 shows the front rack mount base

To ensure a secure mounting of the prototype to the rail, the existing front rack mount base was used to mount the prototype onto. This includes the *t-track lever a* and *t-track lever b, base plate* and the *lock*. The lock is integrated in the *t-track lever a* and when locked this cannot open. This makes sure the carrier cannot be removed from the rack without the key.

4.7.2.5 *Threaded screw*

Figure 36 shows the threaded screw

The screw transferring the rotation to the scissor system have on one side left handed threads and right handed on the other. This was what made the two *link1* parts to move in different directions when the knob was being rotated.

4.7.2.6 *Knob*

Figure 37 shows the knob

The knob is a product that already exists in Thule’s inventory which has a *torque limiter* built in. When the user has put in enough torque, the limiter will engage making it impossible to over-tighten the sprints. The knob is also equipped with a *lock* which when locked restricts the knob to get turned and secures the bike to the carrier, making it theft-resistant.

4.7.2.7 *Scissor system*

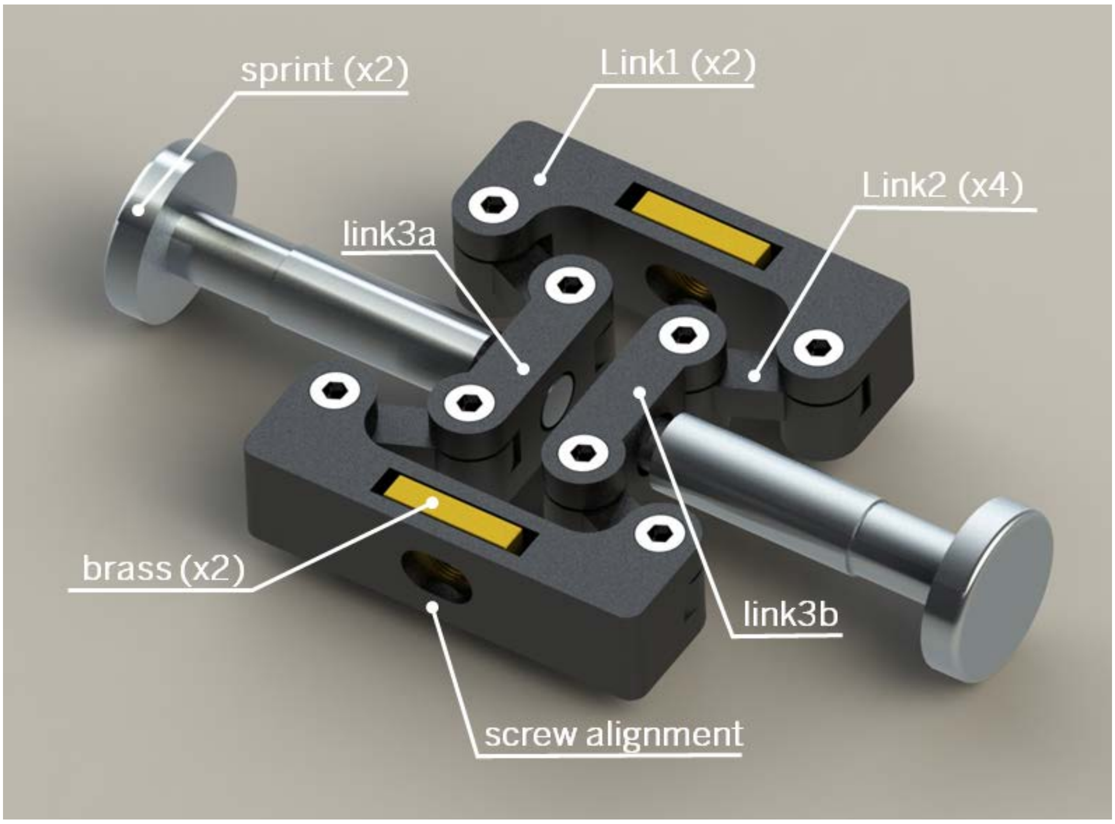
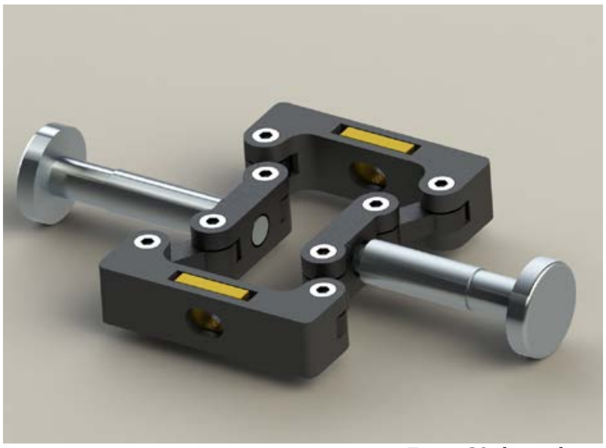


Figure 38 shows the parts of the scissor system



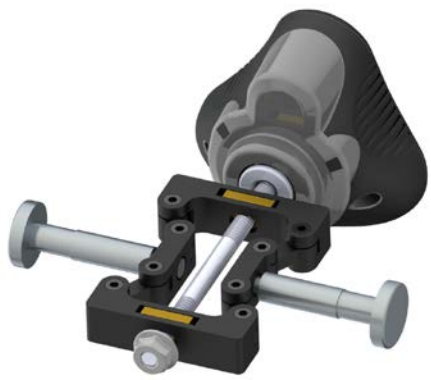


Figure 39 shows the scissor system

The scissor system was constructed in such a way that the tightening force would have a pushing motion acting on *link3a* and *link3b*. This in comparison to the first layout of the concept [4.4.3], where the tightening force acts as a pulling motion, relieves the stress of the internal parts and makes it sturdier. This design also proves to be one of the most compact solutions which was of high value since the space was restricted.

Inserted in both *link1* are two disks. These are threaded to fit the threaded screw and this will let the rotational input engage the scissor system. The disks have room to travel 1,5 mm both directions. This together with the oval cutout, *screw alignment*, will let the entire scissor system to adjust left or right to compensate for deviations in fork bone thickness. This ensures that the total tightening force was equally distributed on both fork bones.

The links, *link1a-b, link2a-b, and link3a-b*, are connected with eight 3 mm allen screws tightened with an associated nut on opposite side. The loose fitting makes for a smooth motion which enables the force transmitting from the threaded screw throughout the system to the sprints. The sprints are in turn connected to *link3a*- and *b* by being screwed together.

4.7.2.8 *Mechanical solution*

Since the double threaded screw and the knob was directly interconnected, turning the knob counter clockwise resulted in an elongation of the jack. This pushed the sprints outwards and made enough space for the front fork to attach. Since the specification state that the carrier shall be able to carry bikes with the front fork thickness of up to 8 mm, the spacing of the sprints are set to maximum of 10 mm. The elongation was a result made possible by the double threaded screw. The rotation caused both of *link1* to unthread which increased the distance between them. This motion caused the carrier to open. When the bike had been placed securely onto the *sprints*, the tightening was done by turning the knob clockwise causing the mechanism to perform the same motion but backwards, closing and tightening the *sprints*. The *torque limiter* will kick in, making it impossible to over-tighten, when the correct force has been applied.

5 Discussion

This chapter will conduct a discussion about the thesis's results and conclusions. The chapter begins with describing the implications that the study resulted in. It then continues with the explanation of how well the requirement specification were met by the two concepts. How the final result answers to the research question are discussed from both of the concepts' perspective. The validity and reliability of the thesis are being analyzed with Olesen's five factors in mind [3.6]. The chapter ends with a discussion on how further work of the project could take form.

5.1 Implications

This thesis resulted in a presentation of potential concepts concerning the front holder of a bike carrier. These concepts could be of use as a foundation for future development of roof mounted bike carrier to the extent Thule consider appropriate. Thule could as well gain an increased understanding about the users' point of view of the Thule Sprint XT product. That understanding could lead to new approaches in future development projects. The construction of Thule Sprint XT consists of many components, which is not beneficial in an economic and wear resistance point of view. Implementation of any of the two presented concepts could lead to increased revenue since the manufacturing probably would be less expensive. This thesis has followed an established design process and the way it has been performed could be used as a guide line for others working on similar projects.

5.1.1 Research questions

5.1.1.1 *Concept 2*

How can the bike be attached to the front of the bike carrier?
With the use of sprints. This was considered, by Thule, to be the best solution for the purpose since the area around the drop outs [Attachment 11, front fork] are made to be able to handle the force applied from the quick release skewer which is equivalent to the tightening force of the carrier.

How can the force that is applied during fastening of the bike be equally distributed on both sides of the fork?
The tightening force will differ between the left respective right fork bones if there are thickness deviations. The forks will, however, never risk getting damaged because of the mechanical properties of the construction limiting the force to not exceed the 3600 N limit.

How can the user be given feedback when the right amount of force has been applied?
Having the system only consisting of the opened and closed position where at the closed position the amount of tightening force will automatically have a value within the range, the feedback is the evident end position. Figure 33 illustrates a similar function where only two positions are possible.

Figure 40 shows Thule Thruride 565 in open and closed position.

5.1.1.2 *Concept 3*

How can the bike be attached to the front of the bike carrier?
With the use of sprints. This was considered, by Thule, to be the best solution for the purpose since the area around the drop outs [Attachment 11, front fork] are made to be able to handle the force applied from the quick release skewer which is equivalent to the tightening force of the carrier.

How can the force that is applied during fastening of the bike be equally distributed on both sides of the fork?
During tightening of the system, *link3a and link3b* will always move the same distance. This means some outer solution had to be added to solve the problem of having equally distributed force on both sides. The answer lies in letting both of the brass parts and the screw to have room to travel 1,5 mm both directions. This will let the entire scissor system to adjust left and right if needed.

How can the user be given feedback when the right amount of force has been applied?
The knob's built in torque limiter will engage when enough force is reached which will emit a clicking sound alerting the user. This will also cause further rotation to skip the gears, making it impossible to over- tighten.

5.2 Validity and Reliability

5.2.1 Olesen's five factors

Verification of validity and reliability in this study have been viewed in the perspective of Olesen's five factors, described in the chapter method [3.6].

The theories that have been used to give this thesis a theoretical foundation, consist of scientific publications. This strengthens the reliability since the theories are known and accepted in the product development community. The theory behind the design process was gained from the book "*Produktutveckling - Effektiva metoder för konstruktion och design*" [2], were the authors have been studying some approaches of different design processes. They have then established a general process that are suitable for many various project. This was because they had presented a range of proven and accepted methods in each phase. The practitioner have the possibility to implement a suitable method which increases the adaptability. The design process in this thesis provides a clear path with the help tools gained from the methods. By using known and accepted theories as the basis of the research, and since this study have been following a stringent design process, this thesis have achieved **internal logic**. The traceability in this thesis's design process, were the followed phases and methods are described both in theory and implementation, enables **applicability** in similar projects.

The objective with this thesis was to present concepts of the front holder of a bike carrier and find a suitable associated design process. Therefore the provided results are both theoretical and practical. The task that led to the research question was given by Thule, who intended to develop the next generation of their roof mounted bike racks. This was due to their vision of keeping on delivering safe and easy-to-use products that meet the market's requirements. Therefore this thesis and its results are highly connected with a real phenomenon which provides the study with **truth.** The thesis provides with **novelty value** as well, since it results in new concepts and a suitable design process that been adapted to optimize the final result.

Due to the scope of this thesis and the time it takes to verify the intention behind the project, it was difficult to prove its **acceptance**. It also depends on the time it requires for the research to reach its final objective and become accepted by the product development community. This is often the case regarding design research, since it requires some time until the product is ready for launching and its properties are evaluated.

5.2.2 Reliability

During this study, some decision making and evaluation have been performed out of intuition instead of undergoing a certain method. As stated in the theory of intuition [2.5], intuition based decisions are often considered useful. They do however not always provide the best result. The amount of prior knowledge and experience are directly connected to the result that an intuition based decision has. An intuition based decision is more accepted the more prior knowledge one has attained. This was for instance the case during the performed tests, since the measuring cell was not fully accurate. But since the testings' main focus was on getting a sense over the user experience, an exact value was not necessary and intuition based decisions could be made instead.

When humans are involved in studies it is necessary to evaluate the results, the selected group of participants and the approach of the test, thoroughly. In the conducted user study and interviews a group of six students were selected. Every one of these students had different experience when it came to road bikes and bike carriers. The participants consisted of both females and males, in the same age group, with different educations and body heights. It could be discussed if the number of participants was enough to get an accurate result. However, since the intention with the study was to give a perception rather than proof, of how the user interacted with the existing Thule Sprint XT, the result was considered to be accurate enough. The interviews were recorded and documented to enable analysis which increased the reliability of them.

During the pilot study, some of the research were based on simple internet research, were the sources was not thoroughly evaluated. This was the case when the background knowledge about bike carriers, road bikes, benchmarking were gained. The intention with this kind of research was mainly to give a prior knowledge to the development and the need to evaluate every source thoroughly was not necessary.

6 Conclusions and recommendations

As can be seen in the specification table [Attachment 6, Requirement specification] concept 2 and 3 have met most of the requirements, however none of the concepts have met all.

6.1 Fulfillment of requirement specification

- *[Easy to use interface]*
  Neither of the concepts had a user study performed and therefore their user interfaces have not been evaluated. The improvements that have been done regarding the user interface consists of design changes to the rotating knob as well as adding turning indications. The new knob design will in contrast to the former knob mediate its function clearly. The previous knob had a design and shape prioritized to cohere with the housing's design in such a way its function became indistinct. This is shown in the result from the user study [Figure 10]. The design changes are thought to eliminate this problem and the additional indications further emphasizes this.

- *[Magnitude of applied force on fork bone (each side)]*
  Concept 3's scissor jack solution did not undergo calculations whether it could achieve an applied force of 3600 N or not. This was because time were spent on investigating and testing this requirement for concept 2 which succeeded to achieve an applied force between the sought value intervals.

- *[Equal force applied to both fork bones]*
  This requirement was not met by the solution offered in concept 2. The requirement was set to exclude the possibility of damaging the fork bones. This was if the situation where thickness differences between left and right fork bones were present. The concept solution does however manage to achieve this demand by never letting the applied force reach outside the magnitude of the applied force range and thereby accomplishing the mean of the requirement.

- *[Load capacity up to 17 kg]*
  Neither concepts were developed to that stage that their load capacity could be tested.

As a conclusion, the only requirement not met was the load capacity of 17 kilograms. All the other requirements were, in the terms of the demands, considered by Thule as met.

6.2 Recommendations

There are improvements that can be done regarding both the user interface and the construction of the mechanism in Thule's Sprint XT bicycle carrier. The interaction of the system have in this thesis been proven to lack the ability to convey its correct way of use in an intuitive manner. To change this, it is recommended to implicate a new way of engaging with the mechanism. As explained for concept 2, having a lever would not only improve the usage of the carrier by eliminating the need of repeatedly having to turn a knob. It would also increase the carrier's intuitiveness because it would then only consist of two positions, opened or closed. By incorporating a mechanism that then automatically would set a correct tightening force when the system gets closed would further improve the simplicity of the product's usage.

6.3 Evaluation of design process

The used design process [Produktutveckling - Effektiva metoder för konstruktion och design] has been easy to implement to this specific design problem. Especially since it has a generic approach, which enables the executor to choose between a wide ranges of different methods in every phase. The design process is structured in such a way that it simplifies traceability. It could have been profitable to have more alternative methods to choose between during the concept generation phase, since it is not always possible to get help from a group of people.

6.4 Further work

The presented concepts that were handed over to Thule are concepts considering the front holder of a bike carrier and not the entire bike carrier. More work is necessary to achieve a product that are ready for launching. Such work would include further construction and testing of prototypes in both FEM-simulations, physical testing, material selection, cost calculations and manufacturing adjustments. Thule puts high value in delivering safe products and therefore all the launched products must pass certain standards and tests. These tests and standards include:

- DIN 75302:1991 – (Roof Racks For Passenger Cars : Requirements And Testing)
- ISO/PAS 11154:2006 – (Road vehicles: Roof load carriers)
- City Crash Test

These have, in agreement with Thule, not been performed since they occur in a stage surpassing the scope of what this thesis was meant to contain. To make sure the product pass these standards are a requirement, later on in the process, for allowing manufacturing.

The performed testing during this project have been restricted by the limited access to equipment and amount of given time. Therefore, it was recommended to perform tests of the sprints with the different engraved grooves more accurate, to verify in what range of applied force that slippage occurs.

Further studies regarding the design of the sprints can be done. This will provide a physical proven result to what solution that will eliminate slippage most effectively.

7 References

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8 Attachments

8.1 Attachment 1, GANTT

planerad tid · verklig tid · Färdig · Oplanerat arbete

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Intro	3	1	2	1	100%
Besöka arbetsplats	3	1	2	1	
Projektpresentation	3	1	2	1	
Förstudie	3	3	4		25%
Konkurrentanalys	3	3	4		
Research	3	3	4		
Användartester	5	1			
Intervju	4	1			
Konceptutveckling	6	3			0%
Brainstorming	6	2			
Skiss	7	2			
itteration					
Koncepteliminering	9	1			0%
Viktning	9	1			
Vidareutveckling	10	6			0%
CAD	10	4			
Prototyping	12	4			
Anmälan	3	1	3	1	100%
Projektplan	4	6			10%
Intrudoktion	5	1			
Problembeskrivning	5	1			
Avgränsning	6	1			
Syfte	6	1			
Problemfrågor	6	4			
Metod	7	3			
Teorier	7	3			
Ganntschema	4	1			
Slutrapport	10	9			0%
Inledning	10	1			
Syfte	10	1			
Frågeställningar	10	9			
Avgränsningar	11	1			
Teorier/Ramverk	11	6			
Metod	11	6			
Resultat	16	3			
Slutsats/Diskussion	16	3			

8.2 Attachment 2, Benchmarking

Manufacturer →	Atera	Yakima	Yakima	Yakima	SportRack	Küat Racks	Rhino Rack	RockyMounts	Whispbar	Elite	Thule	
Product name →	Giro speed	Yakima forklift	SprocketRocket	Viper	SportRack Downshift Plus	Kuat Trio	MountainTrail Bike Carrier	Jet Line	WB200	Sanremo Tour	Sprint	
Product Features ↓												Comments
Price	149	159	189	129	160	209	169	140	289	129	250	US dollar
Torque limitation	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	
Quick release	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	Made for bikes with quick release
Thru-axle compatible	NO	NO	NO	NO	NO	NO	NO	NO	YES (QR 15)	NO	NO	
↑ With adapter	YES	YES	YES	YES	NO	YES	YES	YES	NO	YES	YES	Adapter for bikes with a thru-axle
Weight	2,5 kg	3,2 kg	4,7 kg	2,5 kg		3,2 kg	2,5 kg	2,5 kg	4,2 kg	3 kg	3,6 kg	Of the whole package
Lock	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	Sometimes sold separately
Spacing		100X9 (mm)	100X9 (mm)		100X9 (mm)						100X4-10 (mm)	Possible width of fork
Load capacity	17 kg	15,9 kg	20,4 kg	13,6 kg	17 kg	20,4 kg	15 kg	15,9 kg	17 kg	17 kg	17 kg	Maximum weight of mounted bike
Maximum wheel dimension	29''									29''		On bike
Disk brakes	YES	YES	YES	YES	YES	Leftside	YES	YES	YES	YES	YES	Designed room for disk brakes
↑ Both sides	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	↑ Symmetric or not
Time bike attachment		10 min	10 min	10 min								
City crash test	YES										YES	
Compatible with major crossbars?	YES	YES	Round/Square	Round/Square	YES	YES	YES	YES	YES	YES	YES	Round/Square/Factory
Carbon fibre compatible	NO	YES	YES	YES		YES		NO	?	YES	YES	
One-handed adjustament	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	
The fork need safteytabs		YES	YES	YES	YES			YES	YES	?	YES	To ensure safe mounting
Sceewer	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES	NO	Uses a sceewer

8.3 Attachment 3, Picture of Thule t-track system

8.4 Attachment 4, Thule Thruride 565

8.5 Attachment 5, Observations from user study

Was help needed?	
Person 1	Information about removal of the front wheel was given. The user was trying to mount the bike backwards first. Length adjustment for the rare wheel was not used. Didn't understand the the knob.
Person 2	Did not turn the knob all the way to the click.
Person 3	Did not understand the knob's function.
Person 4	No.
Person 5	Information about removal of the front wheel was given. Did not understand the knob's function.
Person 6	Information about removal of the front wheel was given. Did not understand the knob's function.
Volvo V60	
Person 1	Tried to mount the bike backwards. Didn’t understand the knob’s function. Instead the sprints were tried to press together.
Person 2	Felt obvious how to interact and dismounted the front wheel at once. Had a good low grip. Used the stool. Tightened the back strap first and didn’t notice the rare length adjustment.
Person 3	Took some time to understand the carrier at first. Before trying to mount the bike. Had a good grip. Mounted the front fork first the secured the back wheel. Didn’t understand the knob at first but at last he figured it out. Stopped turning before the click.
Person 4	Took off the front wheel immediately. First mounted the front fork then did the length adjustment. Didn’t understand the knob’s function. Did not turn until click.
Person 5	Didn’t understand that the front wheel were to be dismounted. Bad grip. Back wheel first and didn’t reach properly. Tried to press the sprints together.
Person 6	Didn’t understand that the front wheel were to be dismounted. Adjusted the rare length before mounting. Turned the knob but didn’t feel it had any purpose.
Volvo XC90	
Person 1	Adjusted the rare length. Used stool. Correct mounting.
Person 2	Correct mounting. Used stool.
Person 3	Correct mounting.
Person 4	Better grip than before. No stool. Correct mounting.
Person 5	Better grip. Good mounting. Had to really reach for it.
Person 6	Better grip. Mounted back wheel before front wheel. Forgot about the click.

8.6 Attachment 6, Interview from user study

On what level do you associate yourself with regarding bicycling?	
Person 1	Transportation, pleasure.
Person 2	Transportation, pleasure, training.
Person 3	Transportation, pleasure.
Person 4	Transportation.
Person 5	Transportation, pleasure, training.
Person 6	Transportation.
Have you previously interacted with a race bike?	
Person 1	No.
Person 2	Yes.
Person 3	Yes.
Person 4	No.
Person 5	Yes.
Person 6	No.
Length? (cm)	
Person 1	179
Person 2	176
Person 3	180
Person 4	193
Person 5	168
Person 6	149
Man or Woman?	
Person 1	Man.
Person 2	Man.
Person 3	Man.
Person 4	Man.
Person 5	Woman.
Person 6	Woman.
Education?	
Person 1	Teacher.
Person 2	Lighting design.
Person 3	Industrial design.
Person 4	Product development.
Person 5	Product development.
Person 6	Economics.
Have you previously interacted with a roof mounted bike carrier?	
Person 1	No.
Person 2	Yes.

Person 3	No.
Person 4	No.
Person 5	No.
Person 6	No.
Have you previously used Thule Sprint XT?	
Person 1	No.
Person 2	No.
Person 3	No.
Person 4	No.
Person 5	No.
Person 6	No.
Do you feel that the product mediates the correct use?	
Person 1	So so. The mounting of the back wheel was easily understood. If it is know that the front tire should be dismounted it is easier.
Person 2	Yes.
Person 3	Yes but not the knob.
Person 4	It is mostly understood but the front knob isn't obvious.
Person 5	When you know that the front wheel needs to be taken off.
Person 6	As long as you know that the front wheel should be removed it is logical.
Can you name a positive thing with the product?	
Person 1	The rare wheel mounting.
Person 2	The click that indicated that it was tight enough. The rubber cover of the rare wheel attachment strap. That it was a front fork mounted carrier - esthetic, looks better, streamlined.
Person 3	The click. Short mounting time.
Person 4	It has short mounting time if you know how to do it.
Person 5	It did what it was supposed to. The click.
Person 6	Simplistic. The rare wheel mounting.
Can you name a negative thing with the product?	
Person 1	It felt a bit unsafe.
Person 2	No.
Person 3	There should be a clearer indication of the knob's function.
Person 4	You don't know when you are finished, the length adjustment of the rare mounting and how tight it should be are not indicated.
Person 5	That the knob didn't indicated its usage.

Person 6	Hard to reach.
How easily was the mounting of the bike done first time trying it? *(1=bad, 5=exceptionally good)*	
Person 1	3
Person 2	5
Person 3	3
Person 4	3
Person 5	4
Person 6	2
How easily was the mounting of the bike done second time trying it? *(1=bad, 5=exceptionally good)*	
Person 1	4
Person 2	5
Person 3	5
Person 4	4
Person 5	5
Person 6	3,5
Can you point out any improvements that can be done?	
Person 1	The rare mounting strap feels too plastic.
Person 2	No.
Person 3	Indication for the knob. The rare mounting strap felt plastic and could need an indicator for when the right force is applied.
Person 4	Mount the bike upside down. Have a sticker with instructions on the carrier. Color the rare knob to make it more visible.
Person 5	Sticker showing how the finished mounting looks like.
Person 6	Having the knob giving feedback as it is turned.

8.7 Attachment 7, Requirement specification

Requirement	Value	Testing	Comments	Concept 2	Comments	Concept 3	Comments
User interface							
Mountable on both sides of the car	Yes/No			Yes	The concepts fits the excisting mount which is capable of being mounted on both sides of the car	Yes	The concepts fits the excisting mount which is capable of being mounted on both sides of the car
Interaction with bike carrier at load bar height	0-150 (mm)		Distance from roof rack	55 mm		55 mm	
Operation of tightening mechanism with one hand	Yes/No		One hand is needed to hold the bike	Yes		Yes	
Easy to use interface	>60 (%)	User study	Result impvovements from user study wethear or not all features are understood first time of mounting without	//	This test has not been executed	//	This test has not been executed
Safety							
Force limitating	Yes/No		The system shall be able to restrict the user to not be able to put in to much input force into the system	Yes	The concept uses a solution where the input force can not exceed the sought maximum value	Yes	The concept uses a solution where the turning knob has an biuld in torque limitator. This activates when correct input force is reached
Feedback	Yes/No		Sound or visual feedback when correct force input has been applied	Yes	The feedback is visual. The input has two positions, opened and closed	Yes	When the torque limitator activates, a loud clicking sound gives the user feedback that the correct input force is reached
Magnitude of applied force on fork bone (each side)	600 - 3600 (N)	Modeled in theory with calulations		600 < x < 1450 (N)	Regardless of fork thickness, the applied force always stays within the limitation	//	This calculations has not been executed
Equal force applied to both fork bones	Yes/No			≈No	If fork thickness differ from left to right fork bone the applied force will not be equal, it will however stay within the	Yes	Letting the double threaded screw have the freedom for slight movement sideways the total input force will always be equal on
Security							
Lockable bike to carrier and carrier to roof rack	Yes/No		The carrier shoould not be able to get dismounted from the roof racks without the right key	Yes	The design allows the optional Thule locks to be installed	Yes	The design allows the optional Thule locks to be installed
Geometry limitation							
Fit bikes with disk brakes	Yes/No		The product shall fit most outcomes of disk breaks. Exceptional cases with rare design of disk break or caliper	Yes		Yes	
Fit forks with 9 mm axle	Yes/No			Yes		Yes	
Manage 2-8mm thickness of fork bone	Yes/No		The sprints shall be able to extend 10 mm	Yes		Yes	
Fit existing adapter	Yes/No			Yes		Yes	
Capacity							
Load capacity up to 17 kg	Yes/No			//	This test has not been executed	//	This test has not been executed
Be adapted to be able to handle carbon fibre frame	F < 3600 (N)			Yes		Yes	

Green = Fulfilled
Yellow = Not yet fulfilled. Will be carried out in a later phase
Red = Not fulfilled

8.8 Attachment 8, QFD

THULE® SWEDEN

Technical product study

Project No. XXXXX

Project	Product no / name	Document No.
70400	Thule Sprint __	XXXXX-TPST-XXX
Issued by	**Product type:**	**Page**
Bachelor theasis 2017	Bike mount carrier	
Participants	**Distributed to**	**Date**
Matilda Lundberg & Linus Tjörnevik	Thule Group AB	2017-03-01

Weighting factor

Product Segment:	Perspektive of product:

If demand is:
More important = 1
Equal important = 0,5
Not as important = 0

Exampels of perspective of product:
- End customer life time
- End customer (pre purchase)
- End customer (post purchase)
- Thule
- Retail

0

Demands (WHAT)	Manufacturing cost	Quantity of components	Saftey during mounting of bike	Styling/Design impact	Force limitation	Thru-axle compatible (with adapter)	Feedback during tightening	Equally distributed force	Time for manufactory assembly	Withstand rough handling	Withstand weather/temperature fluctuations	Withstand exposure to UV light	Anti theft secured	Interaction with bike rack at load bar height	Interface for right/left mounting	Easy-to-use interphase	Ability to handle carbon fibre bikes	One hand tightening mechanism	Fit bikes with disc brakes	0	0	0	Weighting factor points
Manufacturing cost		0,5	0,0	0,0	0,0	1,0	0,0	0,0	0,5	0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	1,0	1,0	1,0	5,5
Quantity of components	0,5		0,0	1,0	0,0	1,0	1,0	0,0	1,0	0,0	0,0	0,0	1,0	0,0	0,0	0,0	0,0	1,0	0,0	1,0	1,0	1,0	9,5
Saftey during mounting of bike	1,0	1,0		1,0	0,5	1,0	1,0	0,5	1,0	0,5	1,0	1,0	1,0	0,5	1,0	1,0	0,5	1,0	0,5	1,0	1,0	1,0	18,0
Styling/Design impact	1,0	0,0	0,0		0,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	1,0	1,0	5,0
Force limitation	1,0	1,0	0,5	1,0		1,0	1,0	0,5	1,0	0,5	0,5	0,5	1,0	0,5	1,0	1,0	0,5	1,0	0,5	1,0	1,0	1,0	17,0
Thru-axle compatible (with adapter)	0,0	0,0	0,0	0,0	0,0		0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	1,0	1,0	3,0
Feedback during tightening	1,0	0,0	0,0	1,0	0,0	1,0		0,0	0,5	0,0	0,0	0,0	1,0	0,0	0,5	0,5	0,0	0,5	0,0	1,0	1,0	1,0	9,0
Equally distributed force	1,0	1,0	0,5	1,0	0,5	1,0	1,0		1,0	0,5	1,0	1,0	1,0	1,0	1,0	1,0	0,5	1,0	0,5	1,0	1,0	1,0	18,5
Time for manufactory assembly	0,5	0,0	0,0	1,0	0,0	1,0	0,5	0,0		0,0	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,5	0,0	1,0	1,0	1,0	7,0
Withstand rough handling	1,0	1,0	0,5	1,0	0,5	1,0	1,0	0,5	1,0		1,0	1,0	1,0	1,0	1,0	1,0	0,5	1,0	0,5	1,0	1,0	1,0	18,5
Withstand weather/temperature fluc	1,0	1,0	0,0	1,0	0,5	1,0	1,0	0,0	1,0	0,0		1,0	1,0	0,5	1,0	1,0	0,5	1,0	0,5	1,0	1,0	1,0	16,0
Withstand exposure to UV light	1,0	1,0	0,0	1,0	0,5	1,0	1,0	0,0	1,0	0,0	0,0		1,0	0,5	0,5	0,5	0,0	1,0	0,0	1,0	1,0	1,0	13,0
Anti theft secured	0,5	0,0	0,0	1,0	0,0	1,0	0,0	0,0	0,5	0,0	0,0	0,0		0,5	0,5	0,5	0,0	1,0	0,0	1,0	1,0	1,0	8,5
Interaction with bike rack at load bar	1,0	1,0	0,5	1,0	0,5	1,0	1,0	0,0	1,0	0,0	0,5	0,5	0,5		1,0	0,5	0,0	1,0	0,0	1,0	1,0	1,0	14,0
Interface for right/left mounting	1,0	1,0	0,0	1,0	0,0	1,0	0,5	0,0	1,0	0,0	0,0	0,5	0,5	0,0		0,0	0,0	0,5	0,0	1,0	1,0	1,0	10,0
Easy-to-use interphase	1,0	1,0	0,0	1,0	0,0	1,0	0,5	0,0	1,0	0,0	0,0	0,5	0,5	0,5	1,0		0,0	1,0	0,0	1,0	1,0	1,0	12,0
Ability to handle carbon fibre bikes	1,0	1,0	0,5	1,0	0,5	1,0	1,0	0,5	1,0	0,5	0,5	1,0	1,0	1,0	1,0	1,0		1,0	0,5	1,0	1,0	1,0	18,0
One hand tightening mechanism	1,0	0,0	0,0	1,0	0,0	1,0	0,5	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,0		0,0	1,0	1,0	1,0	7,5
Fit bikes with disc brakes	1,0	1,0	0,5	1,0	0,5	1,0	1,0	0,5	1,0	0,5	0,5	1,0	1,0	1,0	1,0	1,0	0,5	1,0		1,0	1,0	1,0	18,0
																					1,0	1,0	2,0
																						1,0	1,0
																							###

8.9 Attachment 9, PUGH

THULE SWEDEN®

Technical product study

Project	Product no / name	Project No. XXXXX
70400	Thule Sprint __	Document No. XXXXX-TPST-XXX
Issued by: Matilda Lundberg & Linus Tjörnevik	Product type: Bike mount carrier	Page: Pugh Matrix
Copy to:	Distributed to: THULE GROUP AB	Date: 2017-03-01

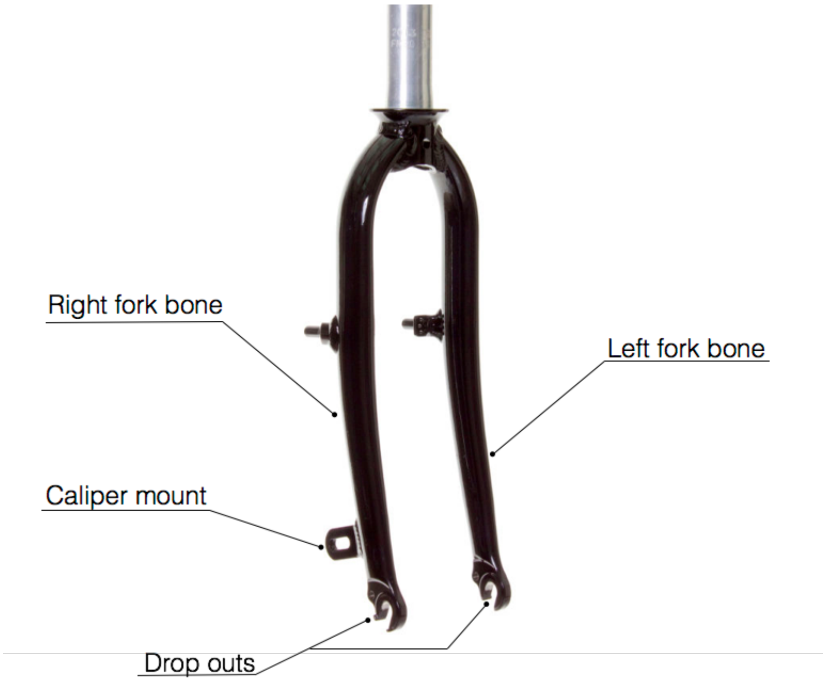
Pugh Matrix

Rating	
Better than reference:	1
Equal as reference:	0
Worse than reference:	-1

	Products (WHO) / End customer demands (WHAT)	Weighting factor points	THULE Sprint XT	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	*Product	*Product	*Product	*Product
			1	2	3	4	5	6	7	8	9	10
1	Manufacturing cost	5,5	0	1	1	1	1	1				
2	Quantity of components	9,5	0	1	1	1	1	1				
3	Saftey during mounting of bike	18	0	0	-1	0	0	0				
4	Styling/Design impact	5	0	-1	1	1	1	-1				
5	Force limitation	17	0	1	1	0	0	1				
6	Thru-axle compatible (with adapter)	3	0	0	0	0	0	0				
7	Feedback during tightening	9	0	1	1	1	1	1				
8	Equally distributed force	18,5	0	1	1	1	-1	1				
9	Time for manufactory assembly	7	0	1	1	1	0	0				
10	Withstand rough handling	18,5	0	1	1	1	0	0				
11	Withstand weather/temperature fluctuat	16	0	1	1	1	0	1				
12	Withstand exposure to UV light	13	0	0	0	0	0	0				
13	Anti theft secured	8,5	0	0	0	0	0	0				
14	Interaction with bike rack at load bar hei	14	0	-1	0	0	0	0				
15	Interface for right/left mounting	10	0	-1	0	0	0	0				
16	Easy-to-use interphase	12	0	1	1	1	1	1				
17	Ability to handle carbon fibre bikes	18	0	0	0	0	0	0				
18	One hand tightening mechanism	7,5	0	0	0	0	0	0				
19	Fit bikes with disc brakes	18	0	0	0	0	0	0				
20	0	2	0									
21	0	1	0									
22	0	####	0									
	Net value		0	84	100	101	22,5	82,5	0	0	0	0

8.10 Attachment 10, slippage test

8.11 Attachment 11, front fork



8.12 Attachment 12, drop out