Concept development of the opening system for Second Storage

A conceptual design for a locking system on a Volvo FH truck

Master's thesis in Product Development

JESPER EDLIND

JOHANNES KLASSON

Department of Product and Production Development

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2017

A MASTER THESIS PROJECT

Concept development of the opening system for Second Storage

A conceptual design for a locking system on a Volvo FH truck

JESPER EDLIND
JOHANNES KLASSON

Examiner: Dr. Göran Gustafsson

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

Concept development of the opening system for Second Storage *A conceptual design for a locking system on a Volvo FH truck*

JESPER EDLIND

JOHANNES KLASSON

Department of Product and Production Development
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone: + 46 (0)31-772 1000

ABSTRACT

An additional feature to Volvo FH trucks is a storage box located above the front wheels which is called Second Storage. Users have complained that the box, especially the opening system, has quality related problems.

This thesis addresses the development of the opening system for Second Storage on Volvo FH trucks. The main purpose of the work is to develop and generate multiple concepts and a CAD-model of a new and improved open/close mechanism to Second Storage. By using data collection methods, interviews and surveys, the customer needs and requirements were elicited. The complex function of Second Storage was decomposed into subfunctions to facilitate the product development process. An idea generation phase was established in order to generate new concepts for each subfunction. By systematic eliminations the most promising concepts for each subfunction were found and combined into a final design.

The final design is a system including a button to trigger the system, a wire to transfer the energy, a rotary latch to unlock and push the lid and two gas springs in order to initiate, control and stop the opening motion. The final design consists of a mix of developed components and chosen standard components. The result of this master thesis is a new improved opening system of Second Storage which communicates a high premium feel by fulfilling the requirements of being robust and reliable.

Acknowledgement

This master thesis has been carried out at the department of Product and Production Development at Chalmers University of Technology, Gothenburg, Sweden, from February to June 2017. The work with this thesis has benefitted from several persons that should be acknowledged.

We would like to express our gratitude to our supervisors Tomas Alexandersson and David Johansson at ÅF, for giving us the opportunity to perform this master thesis. Thank you for your time throughout our development project.

We would like to thank our supervisor and examiner Dr. Göran Gustafsson, who has provided us with guidance and feedback throughout this master thesis. We would also like to thank the participants in the focus group session, for your time and enthusiasm to generate concepts. Finally, thanks to all interviewees who participated in this master thesis, for your time and effort to share your thoughts with us.

Göteborg, June 2017

Jesper Edlind

Johannes Klasson

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

In September 2012, Volvo Trucks released their new premium truck, Volvo FH, which has gone through a major upgrade regarding technology and design compared to the older Volvo FH models. This new FH truck belongs to Volvo's top-of-the-line segment and should communicate quality and a premium feeling.

It is not uncommon that truckers spend weeks in their trucks while working on different jobs. Therefore, the possibility to store personal gadgets and equipment is essential. As a standard component Volvo has developed a storage box called Primary Storage which is located above the front wheels. To create even more storage space, Volvo developed an additional feature to the FH trucks. It is a storage box called Second Storage which is located on the truck's cab just above the front wheels and below Primary Storage. Second Storage is mostly used to store tools and working equipment. The responsible developers of Second Storage have received complaints, from truckers, about its functionality and its lack of communicating premium feel. Furthermore, today's existing design of Second Storage is not optimal. When driving on roads, water and dust can leak into the storage box which results in a jamming locking mechanism.

1.2 ÅF

ÅF is an international consulting firm, founded in Sweden in 1895, operating in numerous sectors such as energy and power, automotive and vehicle, infrastructure, telecom and IT and many more. ÅF offers engineering and product services for the complete development chain.

This thesis has been carried out at a Volvo Trucks section located at one of the ÅF offices in Gothenburg, Sweden. The supervisor at ÅF, Tomas Alexandersson, worked at Volvo Trucks for several years where he was in charge of Second Storage. ÅF is continuously cooperating with Volvo Trucks and this project is therefore executed at ÅF.

1.3 Volvo Group

Volvo Trucks is a part of the Volvo Group which is one of the leading manufacturers of heavy commercial trucks in Europe and in the rest of the world. Volvo was established in 1927 and has grown to more than 100 000 employees. Volvo Trucks is an international company with manufacturing in 19 countries and operates in over 190 markets around the world. Volvo Group's headquarter is located in Gothenburg, Sweden.

1.4 The Aim

The assignment given by ÅF for this thesis was to develop Second Storage. The main purpose of this thesis-work is to develop and generate multiple concepts and a CAD-model of a new and improved open/close mechanism for Second Storage that fulfills the customer needs. The open/close mechanism considers the complete opening of the lid from its initial state of being closed to being fully opened and accessible.

1.5 Delimitations

The development of the open/close mechanism will result in a modelled CAD concept. The delimitations are listed below.

- Only the open/close mechanism of Second Storage is considered in this thesis. The main body and the sealing are therefore excluded.
- Limited access to mechanical equipment and no budget for the development project.
- The development of Second Storage should reach a state of preliminary design with base dimensions and a suggested design of the system.

1.6 Deliverables

- Multiple subconcepts developed and one final concept which is more detailed and modelled to show its functionality using simple CAD models.
- A Chalmers University of Technology approved master thesis where the project's method and findings are documented and presented.

1.7 Report Outline

In the first chapter, Introduction, the thesis is introduced and described. Next, the background and the aim with its delimitations and deliverables are presented. Finally, the outline of this thesis is described.

The second chapter, Methodology, presents and describes the methodology used to develop the open/close mechanism for Second Storage. The methodology followed is mainly proposed by Ulrich and Eppinger and the individual methods and steps are described.

The third chapter, Results, contains the results and findings achieved by following the chosen methodology. Firstly, a pre-study where today's Second Storage and its related problems are brought up. Next, the customer needs and requirements are presented. Lastly, the generated and selected concepts are developed.

The fourth chapter, Final design, presents the final combined concept, the system flow and the technical detail for each component.

In the fifth chapter, Discussion, the methodology used and the results achieved are discussed.

The sixth chapter, Conclusion, presents the final thoughts of this master thesis work and its outcome.

Lastly, the final chapter, Future work, presents recommendations and the final steps in order to develop a complete Second Storage.

2 Methodology

This chapter presents and describes the methodology and methods of which this product development project is built upon. This thesis is based on a pre-defined methodology and suitable changes of applicable methods were made throughout the development process to better suit this project.

The product development process to be followed is based on the methodology presented by Ulrich and Eppinger (2012) in Product design and development. This methodology is beneficial to use in both breakthrough projects and in derivative projects and it fits this master thesis well. The methodology of Ulrich and Eppinger is well known to the students and has worked out well in previous product development projects with a similar purpose.

In the end of each development step, see Figure 1, there is an iterated process where the result and the process are reflected upon to evaluate if there is any way to improve them. This step is at the end of every main phase proposed by the methodology of Ulrich and Eppinger and will not be mentioned again.

2.1 Pre-study

Before starting the product development process, it is important to gather information about the quality related problems and conduct a literature review (Bryman & Bell, 2015). The primary goal of this literature review is to gain knowledge about what is already available on the market and to see what has been written and developed in the specific area. This pre-study was conducted to identify what is already known about the product internally and externally by performing a benchmark of Volvo's competitors and by researching for patents. This type of study will show what type of concepts and theories that are relevant and if there are any inconsistencies in findings related to the area.

2.1.1 Benchmark

According to Ulrich and Eppinger (2012), a benchmark is a comparison between competitors and their relative performance. A benchmark is performed by collecting information about the competitors' storage boxes and comparing them between one another. The comparing parameters, or metrics, can be for instance size, locking mechanism, opening speed etc.

According to Ulrich and Eppinger (2012), a benchmark of competitive products is critical to successfully develop a new competing product and the benchmark can be of value as a rich source of ideas. A benchmark has previously been conducted at ÅF where competing brands such as Mercedes Benz, DAF and Scania were investigated and evaluated. The available pictures and documents are to be used as inspiration for the future concept generation phase.

2.1.2 Patent

Patents are, according to Ulrich and Eppinger (2012), a rich source of inspiration with technical information containing both drawings and explanations of how the described concept works. Patents are generally protected for 20 years from the date of the patent application. These patents must be avoided or licensed. However, patents can be used to find out what concepts and areas that are already covered and protected.

The focus during the patent search was on finding patents related to lock mechanisms such as car door locks, car hood locks, car trunk locks but also on boxes and locks used in other vehicles such as boats, pickups etc. Webpages used to find patents were Espacenet[1], Google Scholar[2] and Svensk Patentdatabas[3].

2.1.3 Field Study

A field study at Volvo Truck's headquarters was established to inspect trucks from both Volvo and Renault (The Volvo Group also provides Renault Trucks) to gather more information about Second Storage and to get inspiration for future development. The inspection was divided into four steps:

---

[1] https://se.espacenet.com
[2] https://scholar.google.se/
[3] http://was.prv.se/spd/

1. How do you maneuver/trigger the opening of Second Storage?
2. Do you, as a user, get the feeling of premium quality when opening the box?
3. Does the opening mechanism provide any feedback?
4. When triggered, does it automatically open or do you have to assist the opening mechanism?

2.2 The Product Development Process

An overview of the development process, presented by Ulrich and Eppinger, can be seen in Figure 1. In cases where the methodology presented by Ulrich and Eppinger is not suitable for the development of this project, other methods were used instead. These methods are described in their respective chapters.

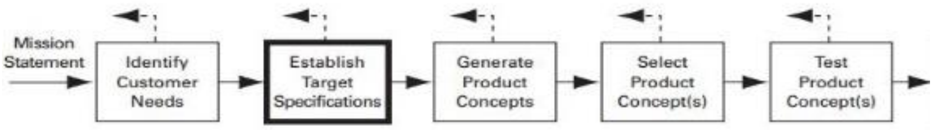


Figure 1: The development process described by Ulrich and Eppinger.

2.2.1 Identify customers needs

The first step in product development is to identify the customer needs and wants. To accomplish this, Ulrich and Eppinger (2012) suggest a high quality channel between the user and the development team. This is done by having a direct contact between the two parts and remove unwanted and unneeded leads. A four-step method is used to gather the needs for a product which begins with a raw data collection and concludes with establishing the relative importance of the needs.

2.2.1.1 Gather raw data from Customer

To be able to identify the customer needs, data from the customers must be gathered. Interviews, focus groups, surveys and sessions observing the product being used are some of the methods to use when gathering raw data from the customer. The goal here is to find information about the customer wants and needs, also unwanted features and aspects of the product are useful. These unwanted features also gives an understanding of what the customer actually wants. Difficulties during the raw data gathering can be to get a hold of the features a customer unconsciously wants or needs such as feelings and subconscious behaviors.

Interviews can be performed in many ways and are generally time consuming since they are often followed by transcribing and analyzes. According to Bryman and Bell (2015), the two main types of qualitative interviews are unstructured and semi-structured interviews. An unstructured interview is when the interviewer prepares topics or just a few questions to let the interviewee freely talk about. The interviewer responds and asks unprepared follow-up questions to make the interview feel like an ordinary conversation. The main benefit of doing an unstructured interview is that the interviewee gets an opportunity to, in a more conversation like way, give his or her point of view (Bryman and Bell, 2015). A semi-structured interview is where the researcher has an interview guide prepared with questions. The specific order of the questions are not of high importance and the researcher may ask questions not included in the interview guide (Wallgren, 2015).

In this project, both semi-structured and unstructured interviews were implemented in order to elicit all the customer needs directly from the source. Truckers were interviewed in order to get more in-depth information of what problems they have with the storage box and also to get their point-of-view of the problems. The team also visited a Volvo workshop to get in contact with truck mechanics to get information about how the storage box is repaired and which parts often need to be repaired. All interviews began with a short introduction of the researchers, the project and the purpose of the interview. Opening questions were asked with the purpose to get to know the interviewee and to give him or her more time to become comfortable as an interviewee.

Surveys are, according to Wallgren (2015), often used as a tool for confirmatory data collection meaning that the purpose is to confirm that data already gathered is accurate. The survey used in this project was published on an online forum for truckers. It was based on a multi choice layout where some questions were follow-up questions, therefore, not mandatory to answer. The layout of the survey was mainly designed in a confirmative manner, but to include explorative answers the participants were allowed to select another option called “other” to formulate their own answers and ideas. The survey included questions about problems related to the current Second Storage, how they use it and what their ideal product looks like. The number of participants that answered the survey exceeded over 70 and the result can therefore be seen as a valid reflection of the customer needs (Wallgren, 2015).

2.2.1.2 Interpret Raw Data in Terms of Customer Needs

According to Ulrich and Eppinger (2012), raw data gathered via interviews and surveys can be interpreted differently depending on the analyzer. Each statement or observation can be translated into several different customer needs. Therefore, it is useful to have more than one team member to analyze and interpret the interview notes and then compare and review one another's list. Ulrich and Eppinger (2012) provides the following five guidelines for writing need statements:

- Express the need in terms of *what* the product must do, not in terms of how it might do it.
- Express the need as specifically as the raw data.
- Use positive, not negative, phrasing.
- Express the need as an attribute of the product.
- Avoid the words *must* and *should*.

These guidelines were later followed in order to write the need statements.

2.2.1.3 Organize the Needs into a Hierarchy

When the raw data is interpreted into a customer needs list it often ends up with many need statements. It is difficult to work with such a large number of needs and thus it is useful to organize and prioritize these needs into a hierarchical list. One way, according to Ulrich and Eppinger (2012), to organize this list can be to divide the needs into primary and secondary needs. The primary needs are the most general needs while the secondary needs are the needs which are to be expressed more in detail.

All need statements elicited from the interviews and the surveys were gathered and grouped depending on their need. Next, each and every needs are ordered into a hierarchy in the group according to how general and similar they are. Lastly, too similar and redundant needs are eliminated or treated as one single need in order to reduce the number of statements.

2.2.1.4 Establish the Relative Importance of the Needs

The next step after organizing the needs into a hierarchy is to establish the relative importance of the needs. This can be done in several ways and Ulrich and Eppinger (2012) presents two different ways in detail. In the first one, the team relies on their previous projects and their experience with customers. In the second one, the importance is based on customer surveys. A customer survey generally takes a minimum of two weeks to complete and it is often worth the time spending to complete it. The survey can be performed in different ways, for instance by email, via the internet, by telephone etc. The purpose of the survey is to let the participants evaluate and rate the relative importance of each need.

2.2.2 Product Specifications

As seen in Figure 1, the specifications are established when the customer needs are identified. The development of the specification is an iterative process where changes are made during the development process. The first step is to set target specifications, which have broad tolerances and values. Later on when more detailed knowledge from the system is gained, a more detailed specification is set. This final specification is more detailed and has a narrow range of values.

According to Ulrich and Eppinger (2012) the specification should describe what the product must do, but not how the product should do it in order to be commercially successful. This means that the criteria should be independent from other specifications and solutions. This gives the opportunity to develop new concepts to satisfy the demands and needs for the product. The needs and wishes in the specifications should be precise and measurable to be able to develop a product that is successful.

To establish the specification list, all demands and wishes from the stakeholders were taken into consideration. The current list of technical requirements from Volvo Trucks and ÅF was analyzed in order to include their requirements of this development project. These requirement, as well as the users' needs and wants, were added to a specification list. The wishes in the list of specification was weighted based on its importance. The weight is derived from what the users found important during the data collection. These weights were controlled and adjusted by ÅF if needed.

2.2.3 Concept Generation

When the customers' requirements are identified and translated into a specification list the next phase in the product development project is the concept generation phase. The goal of the concept generation phase is to generate as many solutions as possible that fulfills the identified customer needs. The results is a set of concepts which are to be screened out to select a final concept.

This chapter includes the four step concept generation method presented by Ulrich and Eppinger. The method, shown in Figure 2 below, breaks down the problem into subproblems in order to make the concept generation less complex. Concepts are generated on each subproblem by searching both externally and internally.

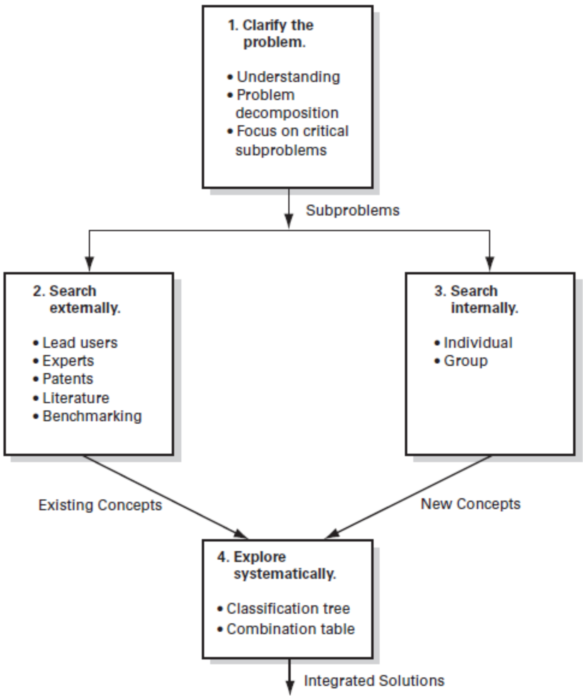


Figure 2: The four step concept generation method.

2.2.3.1 Clarify the problem

The first step in Ulrich and Eppinger's four step concept generation method is to clarify the problem (Ulrich and Eppinger, 2012). By clarifying the problem, the team should understand the problem, see Chapter 3.3.1 Problem decomposition, and try to decompose and divide the problem into simpler subproblems. The initial step of decomposing a problem functionally is to divide the problem into material, energy and signal flows and represent it with the use of a black box. If the decomposition is properly executed, the black box should represent the overall function of the product (Ulrich and Eppinger, 2012).

Once the black box is established, the next step is to decompose the black box into sub-functions where each element describes and represents the overall function that the complete product should fulfill. These subfunctions are expressed in such a way that they do not imply any specific solution to the subfunction. The idea of dividing a complex problem into simpler subproblems is that once solutions to the subproblems are generated and combined, the initial main problem is solved.

2.2.3.2 Search externally

According to Ulrich and Eppinger (2012), searching externally involves searching for already existing concepts and solutions on the market to the identified problem. Even though search externally is listed as the second step in this four step method, this search is constantly performed throughout the whole development process. The external search is basically a structured information-gathering process and can be executed in several ways. Ulrich and Eppinger (2012) argue that there are at least five good ways (see Figure 2 above) of how to gather information during the external search and two of these were used in this project, see Chapter 2.1 Pre-study.

2.2.3.3 Search internally

The next step to generate new concepts is to set up an internal search. In this case, an internal search means using the participants', in the idea generation session, experience and knowledge in order to generate concepts for the different sub-problems stated in Chapter 2.2.3.1 Clarify the problem. To improve the idea generation the participants were informed with the following four guidelines, explained by Ulrich and Eppinger (2012), before the idea generation began.

1. Suspend judgement.

To be able to cover the whole solution space no criticism is allowed on the concepts during the concept generation session. This applies to both the individual generated concepts and on the group's concepts. All the generated concepts are presented, even if they do not seem to be useful in the beginning. This also makes it easier for the participants to present and communicate their concepts to the group when not feeling confident about their generated concept.

2. Generate lots of ideas.

By generating as many solutions as possible the complete solution space is more likely to be covered. By allowing more concepts to be generated, the expected quality of the participants' concepts is lowered. Therefore, the participants are encouraged to share their ideas even if they think their thoughts are not worth sharing. The more ideas that are generated, the easier it is to come up with new ones since they tend to stimulate even more ideas.

3. Welcome ideas that seem infeasible.

Solutions that seem infeasible should also be delivered. These solutions can be "debugged" or applied in other solutions. By presenting extraordinary solutions the boundaries may be stretched and encourage the participants to bring up more ideas. Therefore, even the most infeasible solutions can be valuable and bring up other interesting ideas.

4. Use graphical and physical media.

When working in a group it can be difficult to express ideas by describing them verbally, especially if the participants are from different instances. To help communicating ideas graphical and physical media can be used. In this project sketches were used to help communicating ideas within the group. Other aids that could be used are foams, clays, cardboards and other three-dimensional tools to get a greater understanding of forms and function.

According to McGrath (1984) it is beneficial to individually generate concepts before discussing them in a group, therefore both Brainwriting and the 6-3-5 method are used in this project. Brainwriting is a creative group method developed to give all the participants the same opportunity to come up with solutions. A problem definition is given and the participants are now supposed to write down and sketch their ideas on a paper. After a while, the papers are sent to the next person, which starts to further develop the ideas. This is repeated a satisfying number of times. (Brahm & Kleiner, 1996)

The 6-3-5 method is a group-structured idea generation technique. The numbers 6-3-5 stand for the number of participants, how many concepts each person should develop and how long time it is between the switches. (Johannesson, Persson & Persson, 2013)

Two different internal searches were performed during this project. First, a session where the project team members individually generated concepts and shared their concepts with each other. Next, a focus group session where participants with different backgrounds joined to participate with their knowledge and experience.

A Brainwriting session was carried out by the authors to explore the solution space within the group knowledge and experience. Concepts were generated and described by sketches and descriptions on papers. The concepts were further developed by exchanging the papers with each other to continue the development. This procedure was repeated for all subfunctions, until no more ideas were generated.

To expand the solution space of the problem and broaden the experience input, a focus group session was carried out. An invitation was sent out to engineers working in different fields such as the civil engineering, IT and automotive industry. The purpose of inviting engineers outside of the company was to let people with fresh eyes look into the problem without being biased. The idea generation session was prepared in beforehand to set a plan of what methods to use and how to execute it.

The idea generation started off with a short presentation of Second Storage where some voices of the customers from the data gathering were communicated to the participants. An important factor was not to reveal the solution of the current Second Storage to the participants, due to the risk of locking and limit their creativity to today's solution.

During the idea generation session, a slide-show of inspirational pictures of boxes, lock mechanisms and the intended environment of the product were shown as inspiration to their imagination (Ulrich and Eppinger, 2012). Furthermore, a playlist with fast- and slow-tempo music was played in order to stimulate their creativity and enable them to come up with lots of ideas as well as novelty ideas.

The idea generation method used in the group session was the method explained above, also called the 6-3-5 method. The difference from the method explained was the number of participants and the number of ideas that the participants were allowed to generate for each interval was unlimited. The subfunctions of the storage box were presented and ideas and solutions were generated. Furthermore, some major design limitations were communicated to the participants when needed. After each idea generation session for the different subproblems the ideas were presented and discussed in the group. The session lasted for four hours and the participants were able to present a great number of concepts.

2.2.3.4 Explore Systematically

To synthesize solution fragments and to organize an overview of the solution space a combination table can be used (Ulrich and Eppinger, 2012). This combination table provides a way to consider different combinations of subproblems systematically. The combination table used in this project is a morphological matrix developed by Zwicky in 1969 described in Ulrich and Eppinger (2012). The columns of the matrix describe the subproblems described in Chapter 2.2.3.1 Clarify the problem. Below each subproblem, possible concepts are presented either by sketches or described in words. By choosing one concept for each subproblem, a combined concept is generated. By multiplying the number of concepts for each subproblem the total number of possible combinations of concepts is calculated. Worth noting is that all concepts are not always feasible with each other.

2.2.4 Concept selection

The concept selection phase works as an evaluation phase, with respect to the customer needs, and the goal is to narrow down the number of concepts. The remaining concepts are further developed and eventually one of them ends up being the final concept. Ulrich and Eppinger (2012) presents a two-stage concept selection methodology, one screening stage and one scoring stage. In both stages matrices are used to help the team to systematically go through each concept and rate and rank them according to each other. The screening stage is a time efficient method to get rid of infeasible and inappropriate concepts and aims to produce a smaller number of viable concepts. When the screening stage is completed it is possible to further evaluate and deeper investigate each concept by scoring and rating.

The screening stage begins with a team discussion to come up with arguments in order to eliminate all infeasible and “bad concepts”. When the obviously inferior concepts are eliminated, the next step is to establish an elimination matrix. All concepts are facing criteria and the concepts not fulfilling these are eliminated. The basic criteria can for instance be that the concept:

- fulfills the criteria in the list of specification
- is realizable.

Only the concepts that fulfill all of these criteria or the concepts where more information is needed are kept for further development. The rest of the concepts are eliminated.

The second stage in the concept selection is the scoring stage. To systematically score and rate the remaining concepts a scoring matrix can be used. A scoring matrix can for instance be a Kesselring matrix. Scoring matrices are used as an aid to differentiate concepts, with respect to the customer needs, in the late stage of the concept selection. Criteria derived from the specification list are listed with their weight mentioned in Chapter 2.2.2 Product Specifications. These concepts’ score are later the foundations to a discussion held to choose the final concept.

The approach used in this project was to find criteria and arguments that could eliminate subsolutions one by one and thereby drastically decrease the number of combinations. At first, the most unfeasible and unrealistic concepts were eliminated during a discussion session held by the project team. Concepts from all subfunctions were handled and the approach of this discussion was more or less a verbal elimination matrix. When the worst concepts were eliminated, tables were used to get a further overview of the elimination process.

An elimination matrix was established to decrease the number of concepts of the locking mechanism. Elimination matrices were not needed for the other subfunctions due to the number of concepts eliminated in the first discussion session. The remaining concepts will be compared and evaluated by a Kesselring matrix.

Using these methods to eliminate solutions to each and every subproblem, a final concept fulfilling all requirements for the new open/close mechanism is selected. Next, the final subconcepts are brought into the final design phase, where the interaction between the subfunctions are presented and described.

3 Results

In this chapter the results from all the stages in the methodology chapter will be presented. In order to get a better understanding of the product to be developed, this chapter begins with a pre-study with descriptions of today's Second Storage and its related problems. The pre-study presents solutions on the market, a patent research, a field study and a benchmark. Lastly, this chapter presents the results from the product development process including the customer needs, establishing the product specifications, generated concepts and finally the concept selection.

3.1 Pre-Study

Here, the results from the pre study are presented. They consist of a state-of-the-art analysis, a patent search, a field study and a benchmark.

3.1.1 Today's Second Storage

As mentioned above in Chapter 1.1 Background, Second Storage is an optional feature to the Volvo FH trucks. The box is located above the front wheels, on either both sides of the cabin or only one side. The purpose of the box is to enable more storage to the driver where he/she can store things such as tools and other work related equipment. The storage box is separated into two storage areas, see Figure 3, where a specially designed water tank fits in one of the two storage areas. To open Second Storage the following steps need to be followed:

1. Open the door (driver/passenger door)
2. Push the button located in the doorframe
3. Assist the opening of the lid

Figure 3: A picture showing the two storage areas.

When Second Storage was developed initially, the goal was to keep the manufacturing cost as low as possible, while producing a storage box with high functionality. Over time problems with the locking mechanism and leakage were discovered.

Figure 4: The location of Second Storage.

3.1.2 Problems related to the Second Storage

Second Storage used today could be improved in several areas. As seen in Figure 4, Second Storage is located above the front wheels of the truck. When driving the truck the wheels inevitably transfer water and dust from the road into the wheel arch, meaning the storage box is exposed to these types of difficulties, see Figure 5. Therefore, Second Storage needs to be completely sealed and its components need to be resistant to both dust, particles and corrosion.

The locking mechanism needs to be robust and resistant to dust, water and corrosion. When the truck is brand new the current locking mechanism work as expected. Over time the locking mechanism faces some problems related to dust and water leakage, see Figure 5, which results in an unreliable and slow opening procedure.

Figure 5: A dirty Second Storage due to its exposure to water and dust.

Since the rod, seen in Figure 6, that transforms the force from the button to the locking mechanism is not designed for such a high force, it leads to an unwanted deflection of the rod. Further, when the storage box is brand new the compressed sealing automatically pushes the lid open when the locking mechanism is triggered. When dust gathers and hardens around the sealing the flexibility of the sealing is weakened and the lid stays closed even if the mechanism is triggered. The friction in the locking mechanism, at the arrow in Figure 6, increases due to dust and wear, which results in an increased force needed to unlock the mechanism. In some cases, the lock can jam completely.

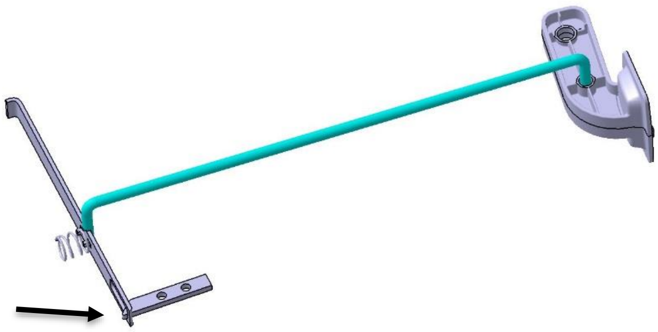


Figure 6: The current locking mechanism with its pushing button.

Today's locking mechanism is, as seen in Figure 6 above, rather simple and specifically developed for Second Storage. Due to the focus to keep the manufacturing cost low and the functionality high when developing the locking system, the components contribute to an unwanted sound when operating the lid. The components generating most of the unwanted sound are the force transfer rod and the rods supporting the lid.

Lindstedt & Burenius (2003) define quality as the ability to maintain the value of the product over time. When the problems above are discovered by the user, the impression of the quality of the product is negatively influenced. The premium feeling that Volvo wants their customers to feel is diminished because of the problems related to Second Storage.

3.1.3 The state of the art

More and more locking systems today tend to be a combination of mechanical structures and electronic systems. The mechanical part with the latch enhances the actual locking of the door, while the electronic system works as the key to unlock and open the door. The opening key can be everything from key cards, fingerprint readers, keycodes and smartphones to simple buttons. (Abus Security Tech Germany, 2017)

Another trend in opening solutions is that the whole opening and closing are a system. When the system is triggered, for example with a sensor, the device unlocks and opens the door automatically. When triggered again, the system goes back to its original position which is closed and locked, meanwhile, the user observes the process. (Volvo Cars Support, 2017)

3.1.4 Patent search

Early on in the project a patent search was carried out. Since this area of development is not revolutionary, new solutions are generally not patented and therefore most of the patents found were either expired or used in other applications. Even though no interesting active patents were found, the team members were given knowledge and inspiration for future development.

3.1.5 Field Study

During the field study the team did for the first time encounter Primary Storage. The overall impression of both quality and functionality was greater than on Second Storage. The main reason for this, was that Primary Storage had a better feedback when operating the lid and automatically opened when the button was triggered. In general, all the main functions were in some way similar to each other even if there were different manufacturers. All systems were triggered with a simple button or a handle. They all had a centered locking mechanism and all were equipped with dampers to control the movement of the lid and to hold it in place.

This was also the first time that Second Storage was encountered when installed and used on an existing Volvo truck. The outcome of this field study was that Second Storage lacked in premium feel. This was mainly because of the locking mechanism, the undamped lid and the squeak and rattle generated when operating the storage box. A correlation was found between the age of the truck and the number of problems with the storage box. The older the truck was, the more complicated it was to operate the opening/closing of Second Storage.

To get more knowledge and inspiration similar applications such as kitchen storages, IKEA solutions and furnitures were studied. This mainly gave inspiration to the upcoming idea generation phase where new approaches to the problem were identified. One of the solutions is shown in Figure 7 below. The solution is a table stopper to a bureau which is installed to dampen the opening and to support the hinges when opened. By adjusting a screw located at the top of the stopper the opening speed (friction) changes.

Figure 7: A table stopper found at IKEA.

3.1.6 Benchmarking

The benchmark was divided into several steps. The first step was to study the benchmark previously done by ÅF where pictures of competitors' solutions of storage areas were taken. The second step was to gather as much information as possible about the competitors' storage boxes on the internet. This information was analyzed in order to understand how competitors solved the problem and also to get inspiration for the upcoming development.

One outcome of this benchmark is that all truck manufacturers studied in this benchmark use one locking mechanism centered in the middle of the box. Another observation made is that all solutions found are fully mechanical solutions and can be seen rather simple. Further, all storages found used dampers to control the movement of the lid and eliminate the unwanted rattle when operating the box. Lastly, the components found on the competitors' storage boxes were usually standard components.

3.2 List of specification

A list of specification was created by using the data gathered from five interviews, over 70 survey participants and the input from ÅF and Volvo Trucks. The complete product specification sheet can be found in Table 1 below. Establishing the product specification list has been an iterative process throughout the complete development project.

	Second Storage		Created: 2017-02-15		Last modified: 2017-04-25 Revision 8.0	
	Functions	**Requirement/Target**	**Type** [Demand/Wish]	**Importance** [1-5]	**Justification** (Extracted from)	**Evaluation/Verification**
1	Technical					
1.1	*Quiet when driving (Squeak and rattle)*	Below 23Hz or between (27-33Hz)	D	-	Volvo	Volvo test rig
1.2	Quiet when operating (Rattle)	Yes/No	W	4	Survey	Prototype
1.3	Reliable locking mechanism	Yes/No	W	5	Survey/Interview	Prototype
1.4	Reliable trigger	Yes/No	W	4	Survey/Interview	Prototype
1.5	Lock is theft proof	Yes/No	D	-	Survey	CAD/Prototype
1.6	Water resistant	Yes/No	D	-	Volvo/Survey/Interview	Volvo test rig
1.7	Dust resistant	Yes/No	D	-	Volvo/Survey/Interview	Volvo test rig
1.8	*Lock is located inside of the box*	Yes/No	W	2	Volvo	CAD
1.9	Feedback when opening	Yes/No	W	3	Survey/Interview	Prototype
1.10	Feedback when closing	Yes/No	W	3	Survey/Interview	Prototype
1.11	Dampened opening	Yes/No	W	5	Survey/Interview	Prototype/Calculations
1.12	Automatically opens when triggered	Yes/No	W	4	Survey/Interview	Prototype
1.13	Lid can be used as a table	Yes/No	W	5	Interview/Volvo	CAD
1.14	Can be opened/closed with one hand	Yes/No	W	3	Survey/Interview	Prototype
1.15	*Maximum length when opened*	600 mm	D	-	Volvo	CAD
1.16	Intuitive opening	Yes/No	W	3	Survey/Interview	Prototype
1.17	*Handle the opening/closing test*	*7100 cycles*	D	-	Volvo	Volvo test rig
1.18	*The lid is able to carry a load spread over the lid area with a maximum deflection of 10 mm.*	*300N (+/- 1N)*	D	-	Volvo	Volvo test rig
1.19	One "push" to open the locking mechanism	Yes/No	W	4	Survey/Interview	Prototype
1.20	Working temperature	-40°C to +50°C	D	-	ÅF	Prototype / CES
1.21	Corrosion resistant	Yes/No	D	-	ÅF/Volvo	CES
1.22	Can handle horizontal impact from objects inside of the box	Yes/No	D	-	ÅF/Volvo	Prototype/CAE
1.23	Automatically locks when lid is closed	Yes/No	D	-	Interview	Prototype
2	Appearance					
2.1	Visual discreet (when closed)	Yes/No	D	-	Survey/Interview	CAD
2.2	Visual discreet (when opened)	Yes/No	W	3	Interview	CAD
2.3	Locking mechanism is hidden to the user	Yes/No	W	4	Survey/Interview	CAD
3	Ergonomics					
3.1	Trigger positioned in a satisfied position	Yes/No	W	3	Survey/Interview	CAD/Prototype
3.2	*Satisfying amount of force is needed for opening*	10N (+/- 1N)	W	4	Volvo	Prototype/Calculation
3.3	Safe to use	Yes/No	D	-	ÅF/Volvo	Prototype
4	Maintenance					
4.1	Can be maintained	Yes/No	D	-	ÅF	Prototype/CAD
4.2	Can be repaired	Yes/No	D	-	ÅF	Prototype/CAD
4.3	Can be easily maintained	Yes/No	W	2	ÅF	Prototype/CAD
4.4	Can be easily repaired	Yes/No	W	1	ÅF	Prototype/CAD
4.5	Easy to clean	Yes/No	W	1	ÅF	Prototype/CAD

Table 1: List of specification.

The product specification is, as written in Chapter 2.2.2 Product Specifications, a list describing what the product should do, but not how it should do it. This list consists of several demands/wishes that needs to be considered when designing the open/close mechanism. A demand is a requirement which needs to be fulfilled and a wish is a desire that the user wish to have. The importance/weight is described in Chapter 2.2.2 Product Specifications. All italicized functions are directly taken from Volvo Trucks' list of technical requirements.

The list of specification is divided into five separate areas where different types of functions are grouped. The different areas are technical, appearance, ergonomics, maintenance and environment. Each area covers its function of the complete Second Storage which is related to this project. In order to keep the solution space as broad as possible a wish from ÅF was to neglect requirements of cost and mass. Another input from ÅF was that the complete locking mechanism system should be of premium quality. According to ÅF, premium quality is a system that is reliable and communicates the impression of robustness. However, premium quality is a complex requirement and difficult to measure. To gather more information about premium quality, the participants in the survey and the interviewees were asked to describe what premium feel is according to them. This information was translated into technical requirements and consisted mostly of reliability and no squeak and rattle.

3.3 Concept Generation

The following chapter presents the result of the concept generation phase for the new locking mechanism system for Second Storage.

3.3.1 Problem decomposition

As mentioned in Chapter 2.2.3.1 Clarify the problem, it is beneficial to decompose the main problem into subproblems. A function model was used to divide the problem into subproblems, see Figure 8. In the initial state (to the left) presented in the function model, Second Storage is closed and in the final state (to the right), the box is opened. The user in the model defines the user's input to the system and the energy defines the functions that need energy to operate.

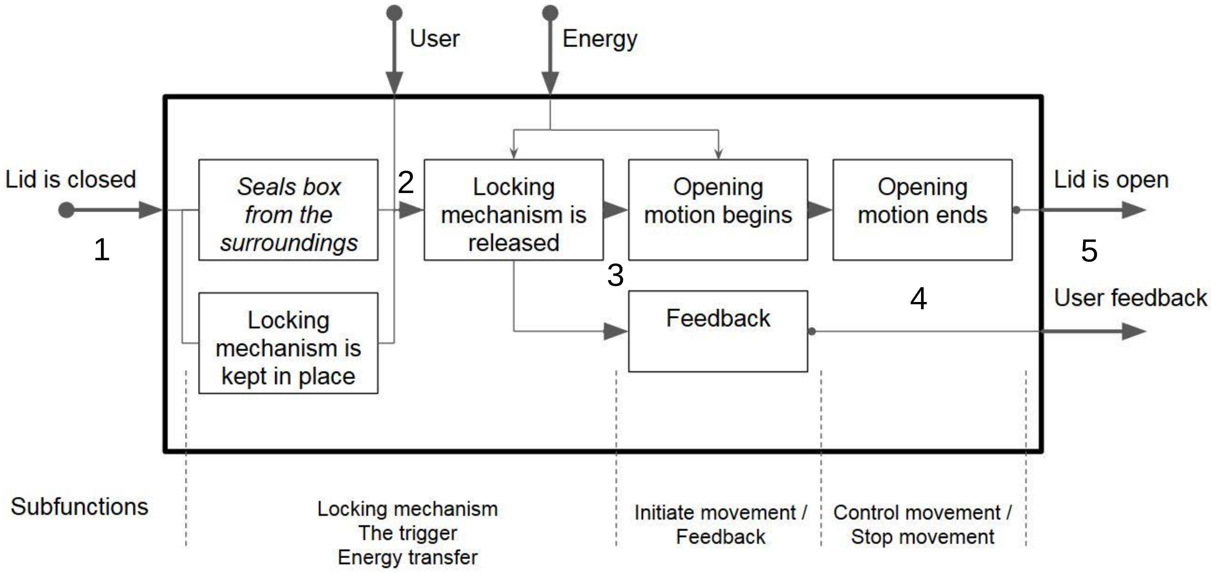


Figure 8: The function diagram of Second Storage.

The opening operation of the box is described as follows:

1. Initial state - The box is locked.
2. The user gives an input to start the opening of the box.
3. The locking mechanism releases and the opening motion begins. The user gets feedback that the opening operation begins.
4. Opening motion ends.
5. Final state - The box is opened.

The sealing is mentioned in the figure above to get a greater understanding of the process, but is excluded from this project, see Chapter 1.5 Delimitations.

The seven subfunctions, which can be seen in Figure 8, are further described below.

Subfunction 1 - Locking mechanism

The first subfunction is the “locking mechanism”. When the storage box is closed the locking mechanism is active to lock and to keep the lid in place.

Subfunction 2 - The trigger

In the subfunction “the trigger” the user interacts with the system and initiates the process to open Second Storage.

Subfunction 3 - Energy transfer

The next subfunction is “energy transfer”. This is the function that transfers the energy from the trigger to the locking mechanism. When the energy reaches the locking mechanism the lock is released and the next function, initiate movement, begins.

Subfunction 4 - Initiate movement

This function initiates the opening motion of the lid. This function is added due to the requirements of “automatically opens when triggered” and “can be opened with one hand”.

Subfunction 5 - Feedback

The function “feedback” communicates to the user whether the locking mechanism is opened or properly closed.

Subfunction 6 - Control movement

Since the complete locking mechanism and opening should be of premium quality it also includes the opening motion. To obtain this, a “control movement” function is added which goal is to control the opening speed and characteristics.

Subfunction 7 - Stop movement

The last subfunction, “stop movement”, supports the lid in its final position to enable the lid to act as a table.

Once the problem was decomposed into subfunction the idea generation phase could begin.

3.4 Generated Concepts

In this subchapter, the outcome of the concept generation is presented. Due to the large number of generated concepts all of them are not presented. Some of the concepts were grouped with each other due to similarities in function and structure. To be able to manage all the concepts generated in the generation phase and to get a visual overview of the solution space, a morphological matrix was established. All generated concepts were titled, sketched by hand and imported to the matrix. The subfunctions described in Chapter 3.3.1 Problem decomposition were presented as columns and the related concepts were listed below. The “locking mechanism” had the most generated solutions and “control movement” the least, 21 respective 5. By multiplying the number of solutions for each column, the total number of combinations was calculated to be over one million. In this case, most of the subconcepts could be combined with each other and each column could therefore be handled and screened independently further on in the project. This matrix was updated throughout the project as soon as a concept was eliminated.

To be able to deliver a final concept all combinations had to be eliminated except one. Difficulties here were to ensure that the right concept in the solution space stood as the final winner. Because of the great number of concept combinations, it was important not to choose concepts in an early stage, due to impossibility to consider all types of combinations.

3.4.1 Locking mechanisms concepts

In this subchapter concepts for locking and keeping the lid in place are presented, eliminated and a final subconcept is chosen.

Rotating Latch

There are different types of rotary latches on the market. Often developed to withstand heavy duty environments and to be robust and reliable. The interesting types in this project are called bear claw and single arm rotary latch. The mechanism releases the lid by rotating the spring-loaded latch and is restored to a locked position by pushing the rotational latch to its initial position. The main difference between the two types is that bear claw uses two rotating latches while the rotary latch uses one, see Figure 9 below.

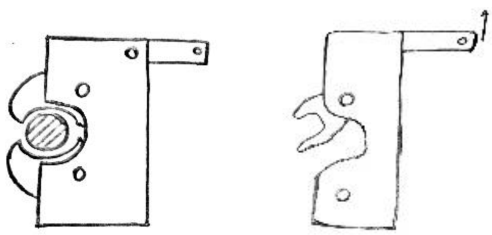


Figure 9: Two different rotating latches.

Pin-in-hole

This solution is similar to the current locking mechanism. One part of the mechanism is fixed on the lid (the pin, 1 seen in Figure 10) and one part is fixed on the storage box (the lever, 2 seen in Figure 10). The lever has a hole in order to keep the lid (the pin) in place. When the pin is positioned inside the hole, the system is locked. To unlock, the lever is released by pushing/pulling the pin away.

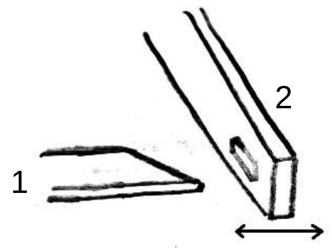


Figure 10: Pin-in-hole.

Grip claw

The “Grip claw” is a novel idea and was generated from scratch during the brainwriting session. The mechanism locks the lid by being pushed inwards and the claw is forced to close due to the supports seen in Figure 11. When triggered for opening the spring pushes the lid outwards and the claw opens and the lid is released.

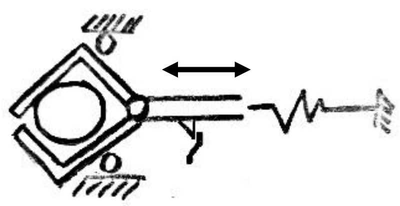


Figure 11: Grip claw.

Door lock

The name door lock comes from the idea of an ordinary door lock. It locks by pushing out a cylinder, see Figure 12 below, which attaches to a hole in the door/lid.

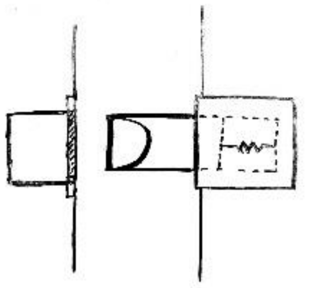


Figure 12: Door lock.

Safety belt

The concept “Safety belt” has the same function as an ordinary safety belt mechanism found in cars. By pushing the tongue plate into the locking mechanism, the components locks. It locks due to a pin that slides into the hole pattern on the tongue plate. By restoring the pin, a spring pushes the tongue plate out of the locking mechanism. See Figure 13 of the concept safety belt below.

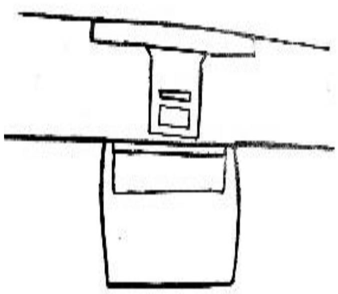


Figure 13: Safety belt.

Magnets

This locking mechanism is based on electromagnets that create an electromagnetic field to attract an iron plate located on the lid/door, see Figure 14 below. When a trigger is pushed the electromagnetic field is disabled which enables the opening of the lid.

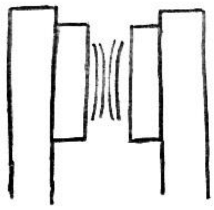


Figure 14: Magnets.

Solenoid

This concept has the same functions as the concept “Magnets” above. The solenoid creates a magnetic field that magnetizes a pin that locks the lid in place, see Figure 15 below. To open the box, the magnetic field is disabled and the lid can be opened. There are standard components on the market similar to this solution.

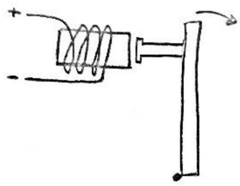


Figure 15: Solenoid.

Ball expansion

The concept ball expansion has some similarities to the grip-claw concept. By pushing the ball-looking pin, located on the lid, to the closed position, the grip is flexed and holds the ball in place, see Figure 16 below. This concepts is found in applications such as indoor drawers.

Figure 16: Ball expansion.

Elimination and scoring of locking mechanisms

To systematically screen out the concepts an elimination matrix was used, see Table 2: Elimination matrix of locking mechanismTable 2. The remaining concepts are listed as rows and should fulfill all columns in order to not be eliminated. The criteria to fulfill were: fulfills demands (see list of specification for demands), realizable, fits in structure, withstands environmental impacts and that enough is known about the concept.

Elimination matrix						
Locking mechanisms	**Fulfills demands**	**Realizable**	**Fits in structure**	**Withstands environmental impacts**	**Enough information**	**Comments**
Rotating latch	Yes	Yes	Yes	Yes	Yes	Further developed
Bear claw	Yes	Yes	Yes	Yes	Yes	Merged with rotating latch
Pin-in-hole	Yes	Yes	Yes	Yes	Yes	Further developed
Magnets	Yes	Yes	Yes	No		Eliminated
Horseshoe	No					Eliminated
Grip claw	Yes	Yes	Yes	Yes	?	Eliminated
Door lock	Yes	Yes	No			Eliminated
Sliding lock	Yes	Yes	No			Eliminated
Rotating pin/hook	Yes	Yes	Yes	Yes	Yes	Merged with rotating latch
Push to release	Yes	Yes	Yes	Yes	Yes	Merged with pin-in-hole
Airplane plate	No					Eliminated
Ball expansion	No					Eliminated
Safety belt	Yes	Yes	Yes	Yes	Yes	Further developed
Squeeze to release	No					Eliminated
Bank vault	No					Eliminated
Solenoid	Yes	Yes	Yes	No		Eliminated

Table 2: Elimination matrix of locking mechanism.

This elimination matrix also includes concepts not presented and described above. The reason for this is that many of these concepts were either eliminated due to not fulfilling the criterion brought up in the discussion or combined with another similar solution. The concepts horse shoe, airplane plate and bank vault are eliminated due to not fulfilling the criteria “automatically locks when lid is closed”. Neither the concept “Electro magnet” nor the concept “Solenoid” can withstand the environment impacts (water and dust) and are thus eliminated. Both concepts “ball expansion” and “squeeze to release” are used in applications where they should open when a horizontal force is applied. In this case, they must be able to withstand a horizontal force without an unwanted opening of the lid since tools and equipment can move freely inside of the storage box and cause horizontal forces to the lid while driving the truck. Since they cannot withstand these horizontal forces, both these concepts are eliminated. The concept “Grip claw” was eliminated because of lack of information about its functionality which would require additional time and research.

In order to compare the concepts and to come up with a final concept different scoring matrices can be used. Due to the fact that many concepts were eliminated and only a handful of similar concepts remain, the team decided to focus on a Kesselring matrix, seen in Table 3. Since the main problem is divided into subproblems the scoring with Kesselring matrices is also done separately on each subproblem.

Kesselring matrix - Locking mechanism								Created: 2017-03-23	
								Modified: 2017-03-23	Version: 1.0
Criteria		**Alternatives**							
		Ideal		**Rotating latch**		**Pin-in-hole**		**Safety belt**	
Function	Weight [1-5]	Value (V)	Total (T)	V	T	V	T	V	T
Quiet when operating (Rattle)	4	5	20	5	20	2	8	5	20
Reliable lock mechanism	5	5	25	5	25	4	20	5	25
Lock is theft proof	5	5	25	4	20	4	20	4	20
Feedback when opening	3	5	15	5	15	3	9	4	12
Feedback when closing	3	5	15	3	9	4	12	4	12
Automatically opens when triggered	4	5	20	5	20	1	4	4	16
Can be opened/closed with one hand	3	5	15	5	15	5	15	5	15
One "push" to open the locking mechanism	4	5	20	5	20	5	20	4	16
Locking mechanism is hidden to the user	4	5	20	4	16	5	20	4	16
Satisfying amount of force is needed for opening	4	5	20	5	20	2	8	5	20
Can be easily maintained	2	5	10	3	6	5	10	2	4
Can be easily repaired	1	5	5	2	2	4	4	1	1
Easy to clean	1	5	5	2	2	4	4	2	2
Total		65	215	53	190	48	154	49	179
Mean		5.0	16.5	4.1	14.6	3.7	11.8	3.8	13.8
Order of priority				1		3		2	

Table 3: Kesselring matrix of locking mechanism concepts.

The criteria in the Kesselring matrix are the ones who seemed to be most important according to the customer needs. The weight of each criteria is extracted from the list of specification, seen in Table 1. The criteria and its individual weighting are described below.

Quiet when operating (Rattle) (4) - Considers the premium feeling when operating Second Storage. According to the users, squeak and rattle highly impacts the quality of the product.

Reliable lock mechanism (5) - Considers the reliability of the locking mechanism. The reliability is important since a non-working locking mechanism is both troublesome and annoying which impacts the perceived quality of the product.

Lock is theft proof (5) - Considers how secure Second Storage (the locking mechanism) is against theft. Tools and equipment stored in the box should not be stolen.

Feedback when opening/closing (3) - Considers the feedback to the user when operating the storage box. The user wants feedback when the locking mechanism is triggered, when the opening initiation begins and if the storage box is properly closed.

Automatically opens when triggered (4) - Considers the opening of the lid. When the locking mechanism is triggered the opening initiation should automatically begin.

Can be opened/closed with one hand (3) - Considers the accessibility of the Second Storage. When the locking mechanism is triggered and released, the lid should open without external help. This makes it possible for the user to open the storage box while only having one hand available.

One "push" to open the locking mechanism (4) - Considers the type of locking mechanism. The locking system only needs to be triggered once in order to unlock the lid.

Locking mechanism is hidden to the user (4) - Considers the location and mounting of the locking mechanism. The locking mechanism should not interfere or block the use of the box.

Satisfying amount of force is needed for opening (3) - Considers the force needed to trigger the system.

Can be easily maintained (2) - Considers the maintainability of the locking mechanism.

Can be easily repaired (1) - Considers the reparability of the locking mechanism.

Easy to clean (2) - Considers how easy the cleaning of the locking mechanism is. Due to the working conditions, the storage box must be cleanable.

Grade	1	2	3	4	5
Quiet when operating (Rattle)	Unwanted squeak and rattle		No squeak		No squeak and rattle
Reliable lock mechanism	Always fail				Does not fail
Reliable trigger	Always fail				Does not fail
Lock is theft proof	Not locked		Easy to open without permission		Secure lock
Feedback when opening	No feedback		Audible or visual		Audible and visual
Feedback when closing	No feedback		Audible or visual		Audible and visual
Automatically opens when triggered	Does not open		Small initiation		Fully opens
Can be opened/closed with one hand	Two hands needed to operate		One hand needed twice to operate		One hand needed once to operate
One "push" to open the locking mechanism	Multiple stages		Two stages		One stage
Locking mechanism is hidden to the user	Fully visible				Hidden
Satisfying amount of force is needed for opening	100N				10N
Can be easily maintained	Complex product				Does not require maintainence
Can be easily repaired	Complex product/Hidden				Easy to change parts
Easy to clean	Complex product/Hidden				Easily accessible

Table 4: Explanations of the grades for the locking mechanism.

In order to grade and rank the concepts equally a grading scale was set based on the list of specification, seen in Table 1. As seen in Table 4 all criteria were linearly graded with a defined grade 1 to 5. To receive the highest ranking, the concept must fulfill each criterion with top grades (5). Moreover, a concept fulfilling each criterion with the lowest grade (1) receives a low ranking. A concept receiving mostly the middle grade (3) is rated as average.

To further eliminate concepts a test and evaluation phase was entered. In this phase a rapid prototyping session took place. Similar existing solutions to some concepts were found in order to enable simple tests of some of the concepts. Since locking mechanisms such as bear claw, rotating latch and safety belt already exist on the automobile market today, the team tested and evaluated these. A car equipped with rotating latches and safety belts was used in order to see how the mechanics work and to determine if they are able to operate as the locking mechanism for the Second Storage.

The locking process was simulated by inserting a rod into the rotating latch to understand how the locking mechanism operates. After simulating this several times, the conclusion that this is a potential locking mechanism was drawn. The same procedure was done to the safety belt. The team had at first difficulties to confirm if a safety belt could be open or not while the mechanism is under tension. The test showed that the safety belt could open while under tension but the level of complexity of the mechanism was too high.

With the knowledge gathered from the tests and the result of the scoring matrix, the team decided that the most promising subconcept for locking the storage box was the rotating latch. The main reason for choosing the rotating latch was the high level of robustness, reliability and simplicity of the solution.

3.4.2 Trigger concepts

Push button/Push button with lever

This concept is a push button which is triggered when pushed. The button can only move in one degree of freedom. The button can be designed as a lever, see Figure 17 below, to increase the generated force to the locking mechanism. A version of this button is found on the existing Second Storage.

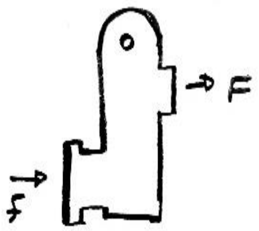


Figure 17: Push botton (with lever).

Pull button with lever

By pulling the handle a force is generated and amplified by using a lever based design, seen in Figure 18 below. This type of button can be found on storage boxes on competitors' trucks. Depending on the design of the button (the placement of the center of rotation), the force generated to the locking mechanism can be either a pulling or pushing force.

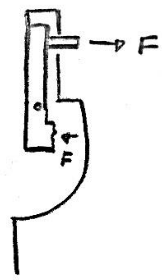


Figure 18: Pull button with lever.

Rotary button

In this concept, the energy is generated by rotating the button which creates a torque. The energy can be transferred from the button in different ways, for instance by rotating an axle or creating a push motion by letting a rod slide on a ramp, see Figure 19 below.

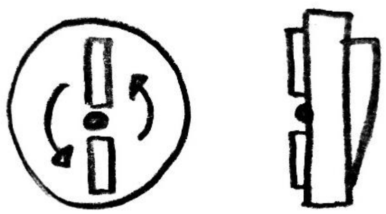


Figure 19: Rotary button.

Sliding button

By sliding the button on a rail the force to unlock the locking mechanism is created. The button can only slide in one degree of freedom, see Figure 20 below.

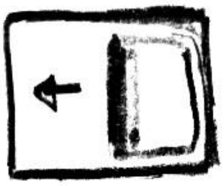


Figure 20: Sliding button.

Electric button / Sensor

By using an electric button or a sensor the system to open the storage box can be triggered, see Figure 21. Worth noting is that this solution requires electricity to be installed to the storage box. Since the concept does not generate a physical opening force, an additional component has to be installed. For instance a magnet, a solenoid or an electric motor.

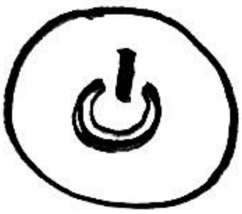


Figure 21: Electric button.

Elimination and scoring of triggers

A discussion was held by the team in order to eliminate as many button concepts as possible. The subconcept “Sensor” was eliminated due to the customers’ needs of having an actual button in order to operate the opening of the box. Furthermore, the subconcept “Electric button” was eliminated because of the solution used on Volvo’s Primary Storage. Since all trucks have Primary Storage installed, while Second Storage is optional, the team decided that the solution on Second Storage should not be more complex than the solution on Primary Storage. Therefore, all concepts with electrical components were eliminated.

The remaining concepts were all mechanical solutions with the same purpose of moving the energy transfer connection from A to B. Due to the complexity of moving one point from A to B with the concept “Rotary button”, the team decided to eliminate the concept. Due to the position of the trigger, a push motion is more intuitive than a pull and a sliding motion. Therefore, the concepts “pull button with lever” and “sliding button” were eliminated and the concept “push button with lever” was kept as the final subconcept.

3.4.3 Energy Transfer concepts

In this subchapter the concepts for transferring the energy created in the trigger to the actual locking mechanism are presented.

Rod/Lever

By using rods the energy can be transferred by either pushing or pulling motions. To increase the force to the locking mechanism, levers can be used see Figure 22 left side. The lever seen in Figure 22, right side, is used in the current storage box and is a simple rod bent in the ends.

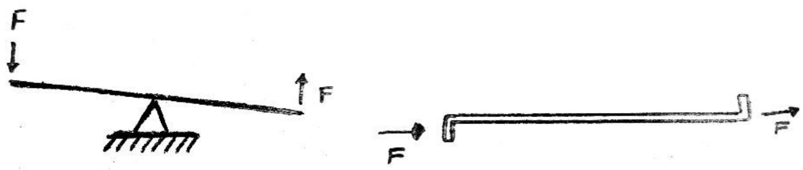


Figure 22: Rod/Lever.

Wire

By using a wire energy is effectively transferred between the components. The force can only be transferred as a pulling force. “The wire” consists of a wire and a housing with at least two supports to keep it in place, see Figure 23.

Figure 23: Wire.

Cog wheel

Cog wheels are a well-used method to gear up forces if needed. Cog wheels can be used in the beginning or at the end of the energy transfer in order to gear up or down the motion and force if needed, see Figure 24.

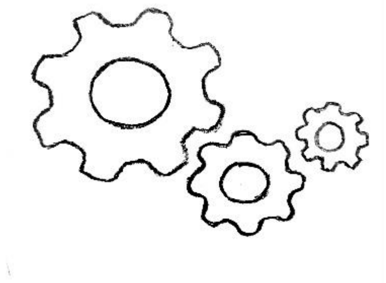


Figure 24: Cog wheels.

Hydraulic

By using the principle of a hydraulic cylinder, seen in Figure 25, the force can be transferred from the trigger to the locking mechanism. This concept can generate high forces in an efficient way and can be found in similar solutions such as bicycle braking systems.

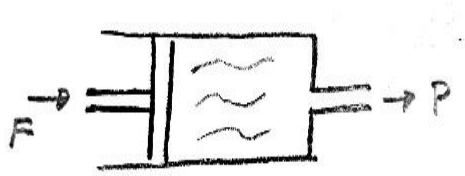


Figure 25: Hydraulic.

Elimination and scoring of energy transfers

The aim was to find a robust and simple solution that fulfilled all needs from the specification list. Since the “energy transfer” function is hidden to the user, the appearance of the product is not considered.

All concepts fulfilled the requirements and can be used as energy transfers for the system. Due to complexity, the concepts “Hydraulic” and “Cogs” were eliminated. The two remaining concepts are simple, reliable and can handle the force needed despite the simplicity of the concepts.

A rod is used on the current Second Storage and there have been complaints about it, see Chapter 3.1.2 Problems related to Second Storage. One complaint is that the rod is flexing when the button is triggered (pushed). Tests were performed on the current storage box to confirm if the problem exists. One reason for the flexing is misalignment between the button and the locking mechanism which creates a bending force in the rod. Tests were also executed on Primary Storage to test the existing wire solution found there. After the tests, the project members could determine that the wire solution is more reliable and gives a higher premium feel to the users than the rod. No flexing occurs in the wire and it feels like operating directly on the locking mechanism when pulling the wire. Other beneficial features with the wire is the flexibility and mobility of the bendable wire to fit in any assembly designs. With the knowledge gained from the tests the team decided to only keep the wire concept as the final subconcept.

3.4.4 Initiate movement concepts

When the locking mechanism is unlocked the opening of the lid is supposed to begin. Here are some of the concepts that handle the "initiate movement" function of the lid.

Sealing pressure

On the existing Second Storage there is no external function controlling the opening of the lid. When closing the storage box, the sealing is compressed which creates a built-in tension, see Figure 26. When opening the lid, the tension in the sealing is released and pushes the lid outwards.

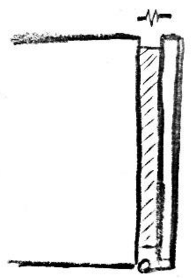


Figure 26: Sealing pressure.

Spring push/ built in

The initiation of movement could be built into the locking mechanism. When unlocking the locking mechanism it also "pushes" out the lid to initiate the opening. This can be done by a built in springs or geometric forms that push the lid open when the locking mechanism is triggered**.**

Gravitational acceleration

By moving the center of mass of the lid with respect to the center of rotation, the gravitational acceleration can be utilized in order to initiate the opening process, see Figure 27 below. This can be done by redesigning the lid and put the bearing structure as far away from the center of rotation as possible. The positioning and design of the hinges can be considered in order to increase the distance between the center of rotation and the center of mass.

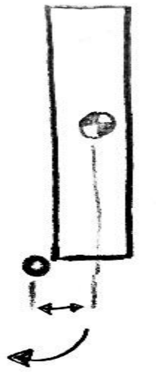


Figure 27: Gravitational acceleration.

Spring loaded hinge

The initiation of movement can be solved by implementing springs in the hinges, see Figure 28 below. The built-in rotational force in the springs will assist the opening motion once the locking mechanism is unlocked and released.

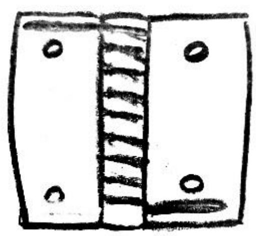


Figure 28: Spring loaded hinge.

Gas spring

The function “initiate movement” can be solved by gas springs creating a pushing force that initiates the opening of the lid, see Figure 29 below. The positioning of the gas spring leads to different characteristics of the opening.

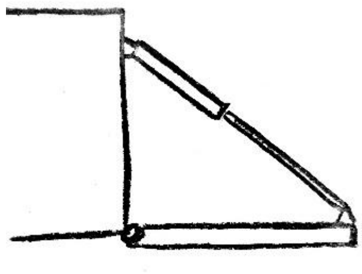


Figure 29: Gas spring.

Magnets

By using electromagnets the magnetic field can be changed from attracting to repelling by changing the poles, see Figure 30 below. The repelling force will create the opening motion.

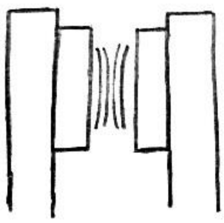


Figure 30: Magnets.

Elimination and scoring of initiate opening

During the first discussion session a number of concepts were eliminated. The eliminated concepts were unrealistic or unfeasible for this product and therefore not presented and described above. After the discussion, the number of remaining “initiate movement”-concepts were of a manageable size and all of them fulfilled the requirements in the specification list. In order to compare and rate the remaining subconcepts a Kesselring matrix was used, see Table 5 below.

Kesselring matrix - Initiate movement														
Created: 2017-03-24 / Modified: 2017-03-24 / Version: 1.0														
Criteria		Alternatives												
		Ideal		Built in push		Gravitational acceleration		Springe in hinge		Gas spring		Magnets		
Function	Weight [1-5]	Value (V)	Total (T)	V	T	V	T	V	T	V	T	V	T
Quiet when operating (Rattle)	4	5	20	5	20	5	20	5	20	5	20	5	20
Feedback when opening	3	5	15	5	15	2	6	5	15	5	15	5	15
Automatically opens when triggered	4	5	20	5	20	2	8	5	20	5	20	5	20
Safe to use	5	5	25	5	25	5	25	4	20	5	25	5	25
Can be easily maintained	2	5	10	4	8	1	2	3	6	3	6	2	4
Can be easily repaired	1	5	5	1	1	1	1	3	3	4	4	2	2
Easy to clean	1	5	5	4	4	1	1	1	1	4	4	4	4
Total		35	100	29	93	17	63	26	85	31	94	28	90
Mean		5.0	14.3	4.1	13.3	2.4	9.0	3.7	12.1	4.4	13.4	4.0	12.9
Order of priority				2		5		4		1		3	

Table 5: Kesselring matrix of Initiate movement.

The grading of the requirements in the Kesselring can be seen in Table 6

Grade	1	2	3	4	5
Quiet when operating (Rattle)	Squeek and rattle		No squeek		No squeek and rattle
Feedback when opening	Adds additional needed force				No influence
Automatically opens when triggered	Does not open		Small initiation		Fully opens
Safe to use	A high risk of accident				No potential accident
Can be easily maintained	Complex product				Does not require maintainence
Can be easily repaired	Complex product/Hidden				Easy to change parts
Easy to clean	Complex product/Hidden				Easily accessible

Table 6: Explanations of the grades for the initiate movement.

All criteria in the Kesselring matrix have previously been used and described in the matrices above, see Chapter 3.5.1 Locking mechanisms concepts. The most important functions for “initiate opening” were “Automatically opens when triggered”, “Quiet when operating (Rattle)” and “Safe to use”. The reason for the high weight on “Quiet when operating (Rattle)” and “Automatically opens when triggered” was because their importance to obtain a premium feeling to the system. The most promising subconcepts to initiate movement were, according to the Kesselring matrix above, “Gas spring” and “spring push/built in”.

When the locking mechanism rotating latch was chosen, tests were performed to find out if an “initiate movement” feature could be built into the locking mechanism. An investigation of a car’s locking mechanisms was conducted to see if there were any features installed to push the door open. The pushing force to initiate the opening of the door is generated by installing a spring in the locking device connected to the rotating latch. When closing the door a tension is built into the spring with the purpose of pushing the door open. The idea of using a spring built into the locking mechanism is kept for further development.

A field trip at Volvo Trucks’ headquarters was executed in order to find out if the gas spring was a good candidate to initiate the opening. One of the investigated gas springs was the current gas spring installed on Primary Storage on Volvo FH Trucks. This gas spring helped to initiate the opening, but the purpose of this gas spring is to support the opening of the storage box upwards (top hinged lid) instead of downwards as Second Storage. This lead to difficulties to compare these two gas springs, due to the difference in characteristics. Instead, gas springs used in other systems such as kitchen storages and drop-leaf tables were investigated. The gas springs in these environments operated smoothly and gave a high premium feel.

The experience acquired from the tests showed that gas springs can be used to both initiate and control the movement of the lid. With this in mind, the team decided to keep the concept “Gas spring” for further development.

The final concept to initiate the opening of the lid is the “built in push” combined with “gas springs”. Since the concept “gas spring” scored the best in the Kesselring matrix and proved to work as expected during the tests, it was chosen as one of the final concepts for initiation. As a result of choosing the locking mechanism rotating latch, which can be equipped with a built-in push, the team decided to combine the gas springs with the built in spring push to ensure the initiation of the lid. When unlocking the rotating latch the spring pushes the lid in the opening direction which enables the gas spring to continue the opening motion.

3.4.5 Stop Movement / Control movement concepts

After initiating the opening movement of the lid the motion must be controlled throughout the process and stopped when fully opened. According to the users, these operations lack the premium feel in the current version of the storage box. To increase the premium feel to these operations the movement should be quiet and dampened, but at the same time not too slow. The most promising concepts from the idea generation sessions are presented below.

Gas spring

To control and stop the movement in a satisfying way gas springs can be used. Gas springs can be modified to fit in different applications where characteristics, such as forces and wanted opening/closing speeds, need to be handled. An illustration of the gas spring is presented in Figure 29.

Rods with friction

Today's current solution uses rods to stop the movement, see Figure 31. To include the control movement aspect into this solution, additional friction could be added to the rods. The friction will help to dampen the opening and thereby control the movement speed.

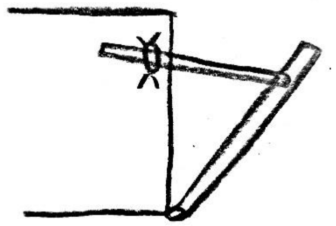


Figure 31: Rods with friction.

Spring loaded hinge

This solution is already described above, see Figure 28, but is also applicable for controlling the movement. The rotational force loaded in the spring will provide a smooth and controlled opening motion throughout the process. To be able to stop the movement and handle external forces a concept or function needs to be added.

Rods with joints

To control and stop the movement several linked rods can be used. The rods are connected through joints with built-in springs to both control and stop the movement, see Figure 32 below. When the lid is fully opened, the rods are aligned and takes up all the force as tension.

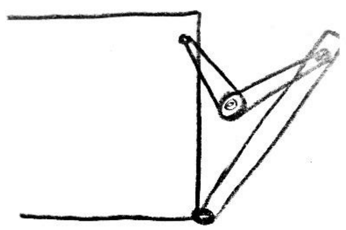


Figure 32: Rods with joints.

Sliding rod in cylinder

The concept “sliding rod in cylinder” is related to the gas spring concept. Instead of using gas, friction is used between the cylinder and rod, seen in Figure 33, to control the movement. When the lid is fully opened a physical stop holds the rod and cylinder in an end position.

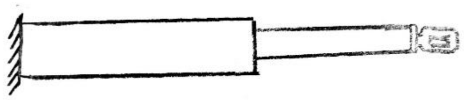


Figure 33: Sliding rod in cylinder.

Wire stop

The stop movement of the lid is solved by installing a wire that stops the opening. This is a simple solution and is easy to implement. One solution is where the wire folds into the storage box when closed and a second solution is a where the wire rolls up when closed, see Figure 34

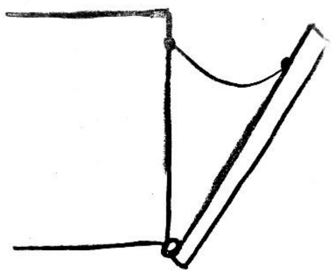


Figure 34: Wire stop.

Rod with spring

The concept “rod with spring” is similar to the rod solution used on the current Second Storage. This concept consists of two versions. In the first version, the springs are attached at the end of the rods, see Figure 35, to dampen the opening by compressing the springs. In the second version, the springs are fastened in the storage box and hooked onto the end of the rods to dampen the opening by extension.

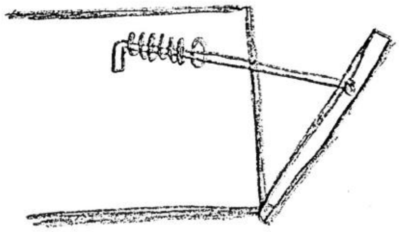


Figure 35: Rod with spring.

Elimination and scoring of stop/control movement

Today's solution to stop/control movement consists of a solid steel rod and added friction in the rod slot to enhance a smooth opening motion, see Figure 36.

Figure 36: Current rods used to control movement.

The concept for the stop/control movement called "friction in rods" was tested. The test was performed on the current Second Storage by covering the steel rods with heat shrinking tubing to increase the friction between the rod and the rod slot, see Figure 37.

Figure 37: Rods covered with heat schrinking tubing.

The conclusion drawn after this test is that the movement might be able to be controlled by friction, but iterations of tests and calculations must be done in order to ensure the correct friction coefficient. Furthermore, it is difficult to ensure a constant friction throughout the complete movement due to the working environment since dust and water have a high impact on the friction coefficient. Therefore, the team decided to eliminate the concept friction in rods and no further development on this concept will take place.

Kesselring matrix - Stop movement		Created: 2017-03-24 Modified: 2017-04-05 Version: 4.0											
Criteria		Alternatives											
		Ideal		Spring in hinge		Gas spring		Rods with joints		Sliding cylinder		Rod with spring	
Function	Weight [1-5]	Value (V)	Total (T)	V	T	V	T	V	T	V	T	V	T
Quiet when operating (Rattle)	4	5	20	5	20	5	20	5	20	5	20	3	12
Dampened opening	5	5	25	3	15	5	25	4	20	5	25	4	20
Lid can be used as a table	5	5	25	1	5	5	25	4	20	5	25	5	25
Can be opened/closed with one hand	3	5	15	5	15	5	15	5	15	5	15	5	15
Water resistant	3	5	15	5	15	4	12	4	12	4	12	5	15
Dust resistant	3	5	15	3	9	3	9	3	9	2	6	4	12
Corrosion resistant	4	5	20	2	8	3	12	4	16	3	12	5	20
Visual discreet (When opened)	3	5	15	5	15	3	9	3	9	3	9	3	9
Satisfying amount of force is needed for opening/closing	4	5	20	4	16	4	16	3	12	4	16	4	16
Safe to use	5	5	25	4	20	5	25	4	20	5	25	5	25
Can be easily maintained	2	5	10	3	6	3	6	2	4	3	6	2	4
Can be easily repaired	1	5	5	2	2	4	4	1	1	4	4	3	3
Easy to clean	1	5	5	2	2	4	4	2	2	4	4	3	3
Total		65	215	44	148	53	182	44	160	52	179	51	179
Mean		5.0	16.5	3.4	11.4	4.1	14.0	3.4	12.3	4.0	13.8	3.9	13.8
Order of priority				5		1		4		2		2	

Table 7: Kesselring matrix of stop movement.

As can be seen in the Kesselring matrix, see Table 7, three of the concepts ended up with high scores and two of them with less points. The concept “spring in hinge” fulfills the requirements of controlling the movement, but lacks the robustness and possibility to support the lid as a table when fully opened. The concept “rods with joints” does not lack one specific function, but the overall scoring is lower compared to the other concepts and it is therefore eliminated. Since the concept gas spring is already chosen as the final subconcept for initiating the opening (see Chapter 4.2.4 Initiate movement), it is ranked even higher than the other two concepts in this case. Due to the fact that no detailed tests between these three remaining concepts can be made, the team decided to only keep the highest scoring subconcept “gas spring” to ensure a controlled opening motion.

The final concept to stop/control the movement is the concept “gas spring”. The concept “gas spring” is in this case suitable since it fulfills both the requirements of stop/control movement as well as the requirements for initiate the opening. In general, gas springs are used for similar applications and are well known in the industry. Gas springs are currently installed on Primary Storage and have, according to the users, a high premium quality feel.

4 Final design

In this chapter the final subconcepts from the concept generation, screening and scoring are combined into a final concept. The final concept is further developed into a CAD-model using the software CATIA V5. The components and the final specification are described in detail and standard components are chosen.

4.1 The system interaction

This chapter presents and describes the combination and interaction between the chosen sub concepts and the system flow.

As previously stated in Chapter 2.2.3.4 Explore Systematically, all subconcepts are independent. Table 8 below, shows how the chosen subconcepts interact and work as a complete system. Furthermore, the table also shows the parent and children relation between the features. Parents can influence and trigger their children but children cannot influence or trigger their parents.

		Connection / Link	
Function / Feature	Solution	Parent	Children
Locking mechanism	Rotating latch	Energy transfer	Initiate movement
Button	Push button with lever		Energy Transfer
Energy transfer	Wire	Button	Locking mechanism
Initiate movement	Spring push / Gas spring	Locking mechanism	Stop/Control movement
Stop/Control movement	Gas spring	Initiate movement	

Table 8: Showing the connection links between the features.

The following list describes the steps how the final system opens and closes:

1. The first step to open Second Storage is to trigger the button with a pushing force. The button is designed as a lever to transform the pushing force into a pulling force.
2. The pulling force is transferred by the wire to the locking mechanism.
3. When the locking mechanism, the rotating latch, is triggered, the mechanism releases the spring-loaded latch which both unlocks and pushes the lid in the opening direction.

4. When the built-in spring initiates the opening, the gas spring begins to contribute to the initiation and continues to control the movement throughout the opening.
5. When the lid is completely open the gas spring stops the movement of the lid and keeps the lid in a supported and stable position.
6. To restore the lid to its original position the user closes the lid by hand while the gas springs are being compressed.
7. When the lid is closed, the rotating latch automatically repositions to lock and keep the lid in place.

4.2 Technical Details

For demonstrational purposes the final solution of Second Storage was visualized with the aid of CATIA V5. Since the design of Second Storage is modifiable and under development, the team decided to model their own version of Second Storage in order to only focus on the purpose of this thesis and to speed up the visualization process. Another reason was that the CAD-model of the existing Second Storage was too complex and unstable to use for further development and implementations. The CAD-model is created to easier communicate the design and details of this final concept. The design of the new Second Storage's body, see Figure 38, is temporary. This chapter also presents the in-depth technical details of the chosen components.

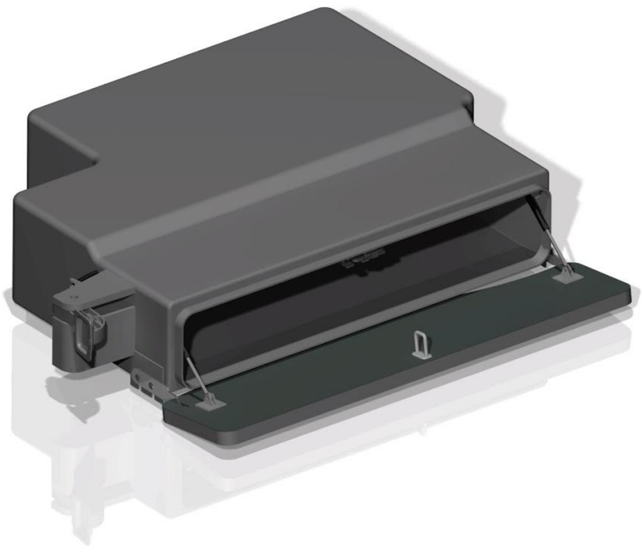


Figure 38: Final design of Second Storage.

Figure 38, shows the digital mockup of the conceptual design of the locking mechanism system. The visualized model has the same outer dimensions and attachment points as the current Second Storage. As seen in the figure, the rotary latch and the hook are located in the center of the box. The modeled box is equipped with the trigger button on the left side and thus mounted on the driver side of the truck (left side).

Figure 39: The modified push button and the connected wire.

In Figure 39, the button and the wire are shown. The wire is connected at the end of the button's lever. The wire is encapsulated in a housing, lead through a hole in the storage box and attached to the locking mechanism mounted inside of the box.

Figure 40: A connected gas spring.

To initiate and dampen the movement a gas spring is attached on each side of the box, as seen in the Figure 40.

4.2.1 Locking mechanism

The locking mechanism is a rotary latch see Figure 41. The component can be either developed in-house or bought as a standard component from multiple suppliers. The cover holds the parts together and gives coverage from the surrounding environment. There is also a safety aspect with the cover which is to prevent the user from getting stuck between the moving parts. The main function of the rotary latch is to lock the lid in place by using the rotating arm to keep the hook in a fixed position. A built in spring is connected to the trigger, see Appendix A, in order to create resistance when pulling the trigger to unlock and open the locking mechanism. The rotary latch comes in many different appearances and versions.

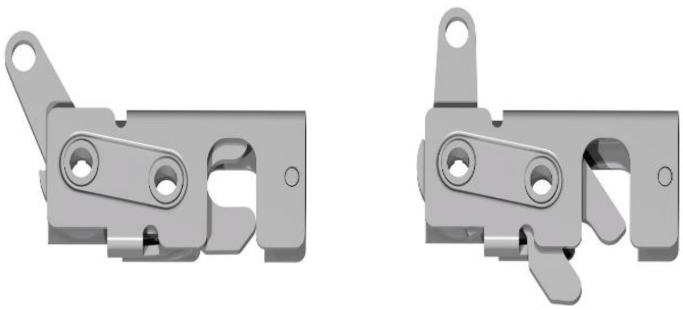


Figure 41: A closed and an opened rotary latch.

The final locking mechanism chosen for this project is a rotary latch from a supplying company, already known by Volvo Trucks, called SouthCo. The rotary latch is a single step lock with model number R4-10-20-501-10. A single step locking mechanism automatically opens when triggered once, which was a requirement for the locking mechanism. The material for the rotary latch is stainless steel. There is also a version of the rotary latch which is equipped with a bumper to decrease vibration and noise. As seen in Appendix B below, the average force to actuate (open) the latch is in the range 20-35 N.

4.2.2 Button

The final button, see Figure 42, is a modification of the existing button, see Figure 6. When accessing the storage box, the user interacts with the button. Therefore, the premium feel communicated by the button is, according to the users, important for the overall impression of Second Storage. To diminish the squeak and rattle when operating the button the tolerances of the mounting can be adjusted. Further, the squeak and rattle can be eliminated by adding a constant tension to the button from the locking mechanism. By having this tension the rattle should decrease and the premium feel of the button will increase. With the tension in the button a feeling of directly operating the locking mechanism is obtained because of to the non-existent play.

Figure 42: The modified push button with lever.

To create a pulling force, when pushing the button, the attachment point is moved to the opposite side of the center of rotation. By decreasing the distance from the wire connection to the center of rotation, the needed force from the user decreases due to an increased lever, see Figure 43. According to the data in Appendix B, the average force to actuate the latch is in the range 20-35 N. With the new design of the pushing button, the distance from the center of rotation to the attachment point is 26 mm and the distance from the pushing interface to center of rotation is 70 mm. With the assumptions of no friction in the system and the actuating force of 20 N and 35 N, the pushing force to trigger the locking mechanism is calculated to be between 7.43 N and 13 N, see Table 9.

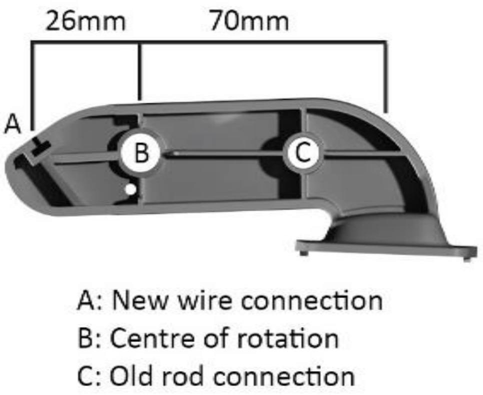


Figure 43: New dimensions of the modified push button with lever.

#: R4-10-20-501-10	Worst case	Best case
Actuating force (to open latch) [N]	35	20
Length from push to centre of rotation [m]	0.07	0.07
Length from wire pull to centre of rotation [m] (attachment point)	0.026	0.026
Pushing force on button [N]	**13**	**7.43**

Table 9: New forces needed to open Second Storage.

4.2.3 Energy Transfer

The energy transfer is completely hidden to the user, though important for the system to work and to communicate a premium feel. The final energy transfer solution is, as mentioned in Chapter 3.5.3 Energy Transfer concepts, a common wire, see Figure 44. The wire is covered with a housing to protect it from environmental impacts as well as to make it possible to route the wire. The ends of the housing are fixed to transfer the force without moving the housing. Benefits of a wire are that it is simple and flexible to fit Second Storage regardless of its design, since the wire can be bent and modified to fit the structure. This enables the locking mechanism to be mounted inside of the box so that it is covered from the surrounding.

Figure 44: An illustration of the final wire.

In order to fasten the wire, see Appendix C, a link retainer and cable mounting bracket, see Figure 45, needs to be installed. Specifications for these can be found in Appendix D and Appendix E with model number R4-0-43922 and R4-0-50253-1.

Figure 45: The cable mounting bracket and the link retainer.

4.2.4 Initiate movement

To ensure an opening initiation of the lid a “built in push” and gas springs are added. The “built in push” is installed inside of the rotary latch and the gas springs are mounted between the lid and the storage box. The initiation begins when the button is pushed and the locking mechanism is released, see Figure 46. The pre-tensioned spring connected to the rotating arm is released to initiate the movement of the lid. The rotating arm pushes the hook outwards which initiates the opening movement of the lid. When closing the lid a tension is generated in the spring attached on the rotating arm in the locking mechanism. When the rotary latch is unlocked and released a gasket force of 100N is pushing the lid outwards, see Appendix B.

Figure 46: Overview of the locking mechanism being closed and opened.

When the angle between the lid and the storage box increases, the gas springs begin to support the initiation and opening by pushing the lid further away. One critical aspect when using the gas springs is the deflection of the lid caused by the constant force from the gas springs. By installing the mounts to the gas springs close to the hinges on the lid, see Figure 40, the force is absorbed and the deflection of the lid is minimized.

4.2.5 Control movement

To control the movement when opening Second Storage, two gas springs are mounted on the inside on both sides of the storage box. When the opening motion is initiated by the rotary latch, the two gas springs are actuated to control the opening motion and dampen the lid. As mentioned in the Chapter 4.2.4 Initiate movement, the gas springs pushes the lid open. If the opening motion is too slow, the gas springs increase the acceleration by pushing the lid outwards. If the opening motion is too fast, the gas springs operate as dampers to decelerate the opening speed of the lid. Once the lid is fully opened, the gas springs support the lid in order to maintain at a horizontal table position. The distance between the mounts of the gas spring varies between 110mm to 133mm depending on the position of the lid. The maximum stroke length is 23mm, see Figure 47. Further, the gas springs can be covered with a sealing to be protected against water and dust if needed.

Figure 47: Illustration of the final gas spring.

4.3 Final Specifications

In the following chapter criteria from the specification list are gone through and presented if fulfilled or not. A comparison between the current Second Storage and the final concept is carried out.

The first criterion to fulfill was the “Quiet when operating (Rattle)”. This criteria is difficult to evaluate for multiple reasons. To be able to measure values for squeak and rattle a final prototype needs to be built and equipment to measure sound level needs to be available. The largest reason for the squeak and rattle in the current version is the energy transfer rod and the control movement rods. These are today connected with wide tolerances and generate a lot of unwanted noise. In the new system these components are exchanged to a wire and gas springs. These components are constantly under tension, which drastically decreases the squeak and rattle.

According to the users the reliability of the system is of high importance. One example of reliability is that a consistent trigger force should always unlock and open the lid. The requirements related to reliability is “Reliable trigger” and “Reliable Locking mechanism”. The largest problem with the existing storage box is the reliability issues with the locking mechanism. After some usage the lock starts to jam and the reliability decreases. By installing the rotary latch and the wire the reliability of the whole system should increase due to the new standard components. The new wire is not negatively influenced by the applied force. Instead, the wire directly transfers the energy to the rotary latch which, according to SouthCo, actuates with an opening force between 20N and 35N.

Another important feature from the users is the “Feedback when operating”. The user wants an indication that tells if the system is properly closed or opened. When closing the lid on the current second storage, it is hard to tell if the lid is properly closed. In the final concept, there are two features pushing the lid open when the button is triggered or when the locking mechanism is not properly closed. These features are the built-in spring in the rotary latch and the gas springs. If the locking mechanism is not properly closed the lid will be pushed open again. By adding these features, the feedback is ensured by eliminating the states between fully opened and completely closed.

According to the users the lid should have a “dampened opening”. The current dampers are rods with added friction to the contact area. The added friction does not fulfill the requirement “dampened opening” due to the uncontrolled opening motion. The final solution gives the lid a dampened opening because of the controlled motion provided by the gas springs.

One of the focuses in this project was to develop a concept with premium feeling. As mentioned in Chapter 3.2 Product specification, premium feeling according to the customers are robustness, reliability and quiet when operating. Squeak and rattle when operating are not allowed due to their negative impact on the overall quality. The reliability is important since the mechanism should operate as expected. To increase the premium feel components fulfilling the requirements were chosen and integrated to the system. The wire and the gas spring should generate less rattle than the previous components and the new rotary latch should provide a robust and reliable mechanism compared to the current locking device seen in Figure 6. This should result in an opening system fulfilling all the requirements in the list of specification, seen in Table 1.

5 Discussion

In this chapter the methodology and results of this master thesis are discussed.

5.1 Method

The approach of this master thesis follows the common guidelines for a development project taught at Chalmers University of Technology. The methodology is based on the product development process proposed by Ulrich and Eppinger (2012). We are overall satisfied with the chosen methodology and it has proven to be a good choice since it is applicable in this type of product development project. To gain a deeper understanding of specific tools and methods other sources of information were studied to establish a complete product development chain. The size of the framework for this master thesis has been adequate for the time given.

The chosen data collection methods, interviews and surveys, allowed for a great way to gather raw data. By combining these methods, both exploratory and confirmatory analyzes were conducted. In order to get a deeper understanding about the customer needs and requirements, more interviews could be conducted. Furthermore, some survey questions were hard to interpret in terms of understanding and get valuable information out of their answers. The reason for this was how the questions were formulated in the survey and the participants will to contribute and elaborate their answers. However, we are still more than satisfied with the result of the interviews and the survey. A lesson learned is to put more time and effort into formulating a survey in order to avoid vague and unclear responses.

The initial plan with this project was to implement tools from lean product development, such as early tests and evaluation phases in order to eliminate time-consuming and unfeasible solutions. This method was excluded, due to the non-existent budget, which made it impossible to buy standard components to test and evaluate the concepts. A big part of the project development courses at Chalmers University of Technology taught us that testing, especially in an early phase, is a cost and time efficient tool in order to evaluate and eliminate concepts. Since no budget for the development of this project was available, it resulted in an elimination phase with difficulties to eliminate concepts. Since the number of concepts were so many, our approach to eliminate was to find arguments and reasons to prove that the specific concept was bad or infeasible.

The concepts were more or less eliminated based on secondary data found on the internet and by performing simple tests which may not reflect the reality of the system.

The development process and the method could differ if a direct contact with Volvo trucks was established during the early stage of the project. Pre-studies, customer needs and earlier evaluations from customers may have been accessible, which would have helped the startup of this project. If a greater understanding of the processes used to develop and manufacture the current Second Storage would have been available, it would contribute to our knowledge of Second Storage and facilitate our development project.

5.2 Results

The result in this project is a conceptual opening system for Second Storage for Volvo FH trucks. The new system should be a more functional and robust system with an increased premium feel. The solution is still a mechanical and simple system which communicates the same design language and characteristics as the rest of the truck.

When ÅF gave us the project frame, we were told not to consider the cost when generating and selecting the final concept. The reason for not considering the cost was to fulfill the requirement to obtain a premium feel and at the same time cover the whole solution space. The cost consideration resulted in a wide framework of the project which was difficult to cover. It was possible to focus on revolutionary, high tech, ideas that needed lots of development to be implemented in future trucks. Another possibility was to aim for a robust and simple solution to replace the current solution. In a later stage of the development we decided to focus on solutions that could be implemented and replace the current solution.

If the cost of Second Storage would be considered, the final concept could have been totally different in respect to the development process and the final design. The chosen components may have been developed and designed instead of bought as standard components. Further, development cost and manufacturing cost could have been calculated and analyzed in order to identify a tradeoff between cost and performance.

When entering the elimination and scoring phase, the team realized that the final solution for this project does not need to be a revolutionary solution. If the team would have realized this early on in the project, less time and effort would have been spent during the concept generation phase, especially since all of the revolutionary solutions were eliminated. The time given could have been used to conduct a more detailed pre-study to find already existing solutions or to investigate the customer needs more thoroughly which could result in different solutions.

Once the final concept was selected a visualization of the model was created in Catia V5 in order to communicate the design and implementation of the chosen components. The original model of Second Storage was given from the company to enable an implementation of the new system. The original model was not used as the final model, mainly because of the complexity to modify and implement the final solution due to the structure of the model. Secondly, the company told us that the current second storage should be redesigned if a new solution of the opening system was found. Therefore, a simplified model with the same base dimensions as the current second storage was created to implement the new opening system in order to show that the new components can work as a system. However, if the original model could have been modified and used, the implementation of the new system could have been more precise and all chosen components could have been selected and dimensioned to a final state.

The biggest challenge in this project was to define and provide the premium feeling. During the introduction meeting about Second Storage with the supervisor at ÅF, we were informed that Second Storage should communicate a premium feeling. Since premium feeling is difficult to measure, we wanted the users' interpretation in order to translate the feeling into a technical requirement. To communicate a premium feeling, Second Storage should be reliable, robust and quiet.

In order to deeper investigate the premium feeling of the system, more in-depth tests need to be performed. One expected step in this project was to build a prototype to enable tests to evaluate the final system. As the project continued, we realized that many of the components in the final system were standard components that could not be built, because of complexity, in the workshop available at Chalmers University of Technology. Without a budget, the standard components such as gas springs, wires and rotary latches could not be bought and therefore no tests could be performed. A test rig or prototype would make it possible to perform tests on the final system and on subconcepts, which could help to confirm data.

6 Conclusion

The goal of this master thesis was to develop and generate a CAD-model of a new and improved open/close mechanism to Second Storage. The new concept should fulfill the criteria gathered from the company and the customers where the main criteria were robustness, reliability and obtaining a premium feel.

By following the methodology presented by Ulrich and Eppinger customer needs were elicited by conducting interviews and surveys. Concepts were later generated and screened until one final concept was left. The final concept is a preliminary design with developed components as well as chosen standard components.

The final subconcepts should be more reliable and have a higher premium feel than the existing solutions. However, it is not certain that the final concept is better than the current solution since more comprehensive tests are needed in order to determine how the final concept works as a complete system.

The final conclusion of this master thesis is that Second Storage on Volvo FH trucks can be developed in order to fulfill the needs and requirements from Volvo, ÅF and the users.

7 Future Work

Since the aim of this project was to develop and generate a CAD-model of a new and improved open/close mechanism to Second Storage, and not a final product, there is more work to be done before choosing this as the next open/close mechanism.

- A future developing project with the purpose of designing a completely new model and layout of Second Storage, where the results of this thesis work could be implemented.
- Customer needs should be investigated more thoroughly prior to a future development project.
- When the design of the new Second Storage is completed, manufacturability, manufacturing cost, material selection and packaging should be taken into account.
- As seen in Chapter 4.3 Final Specifications, the chosen concept fulfills the requirements in the list of specification in theory, but to be able to verify and evaluate this concept against today’s solution the first step would be to build a functional prototype. The prototype would help to confirm that all components work together as a system.
- A deeper investigation of premium feel needs to be done in order to get a greater understanding and measurable requirements.
- Finally, more comprehensive tests are needed in order to verify and ensure that all the requirements in the specification list are fulfilled.

References

Abus Security Tech Germany, Modern locking systems are secure, convenient and innovative, retrieved 2017-02-17, from https://www.abus.com/eng/Guide/Break-in-protection/Locking-systems

Brahm, C. & Kleiner, B. H. (1996). Advantages and disadvantages of group decision-making. *Team Performance Management. 2*(1).

Bryman, A., & Bell, E. (2015). *Business research methods*. Oxford (UK): Oxford University Press.

Johannesson, H., Persson, J., & Pettersson, D. (2013). *Produktutveckling: effektiva metoder för konstruktion och design*. Stockholm: Liber.

Lindstedt, P. & Burenius, J. (2003). The value model: how to master product development and create unrivalled customer value. Ödesborg: Nimba

McGrath, J. E. (1984). *Groups: interaction and performance*. Englewood Cliffs, NJ: Prentice-Hall.

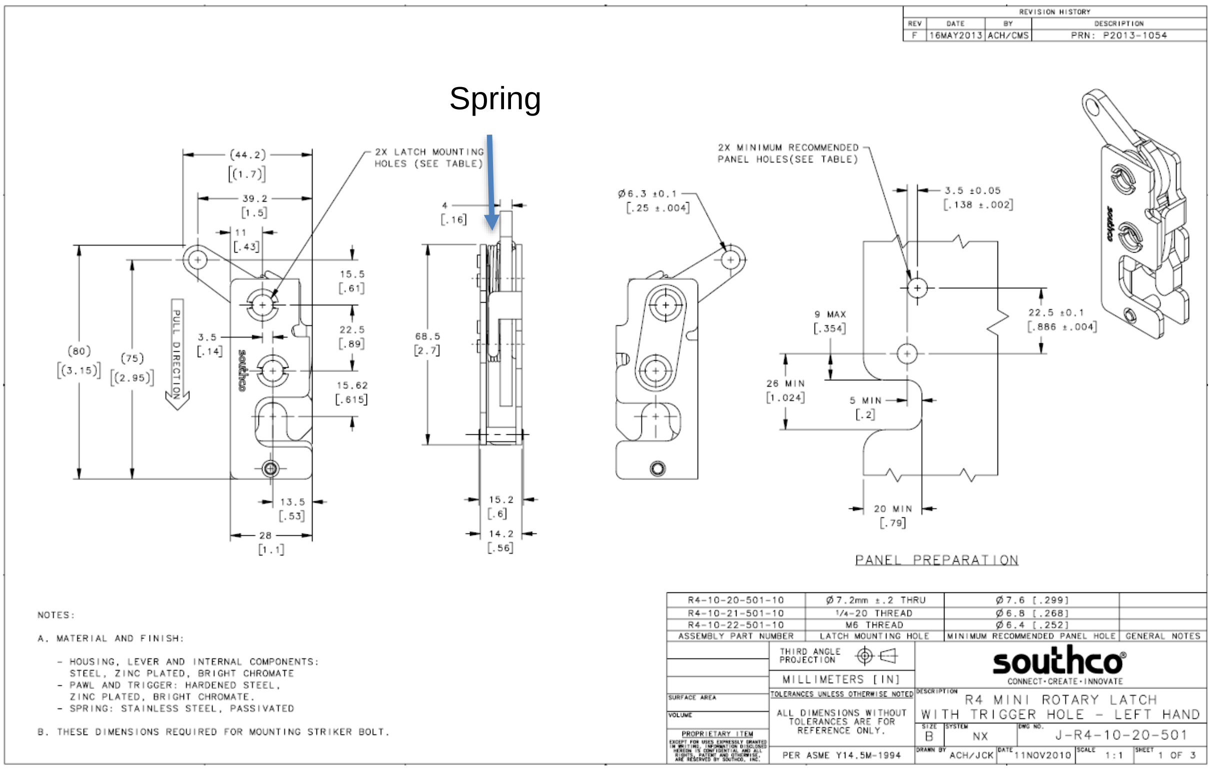
Ulrich, K. T., & Eppinger, S. D. (2012). Product Design and Development (5th ed.). New York: McGraw-Hill Education.

Volvo Cars Support, Foot movement tailgate operation, retrieved 2017-02-17, from http://support.volvocars.com/en-CA/cars/Pages/owners-manual.aspx?mc=v526t8hbat&my=2016&sw=15w46&article=3cb4b97661c71e4ac0a80151737cdd58

Wallgren, P. (2015). Qualitative methods - Data collection. Gothenburg, Sweden. Retrieved November 11, 2015

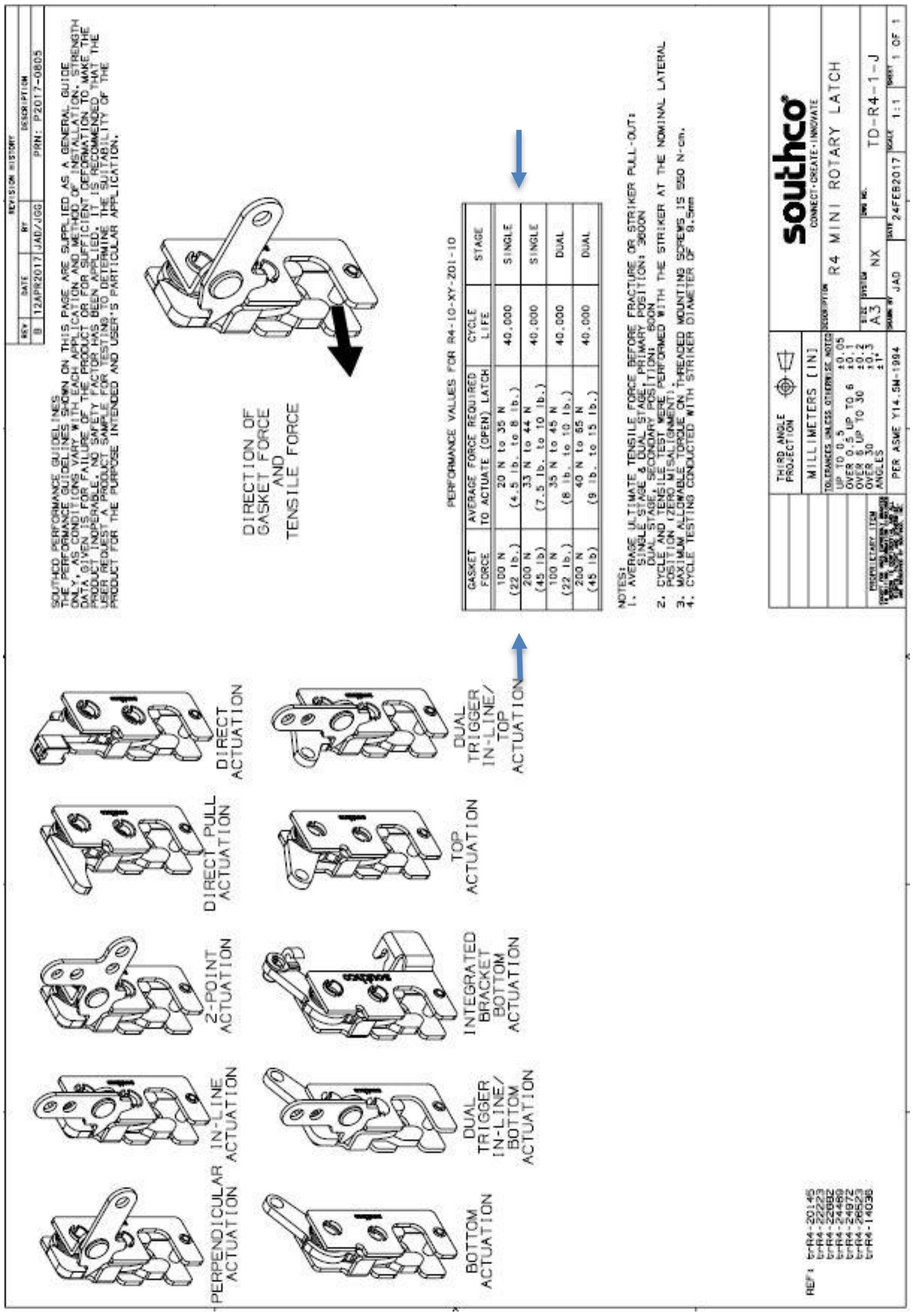
Appendix

Appendix A



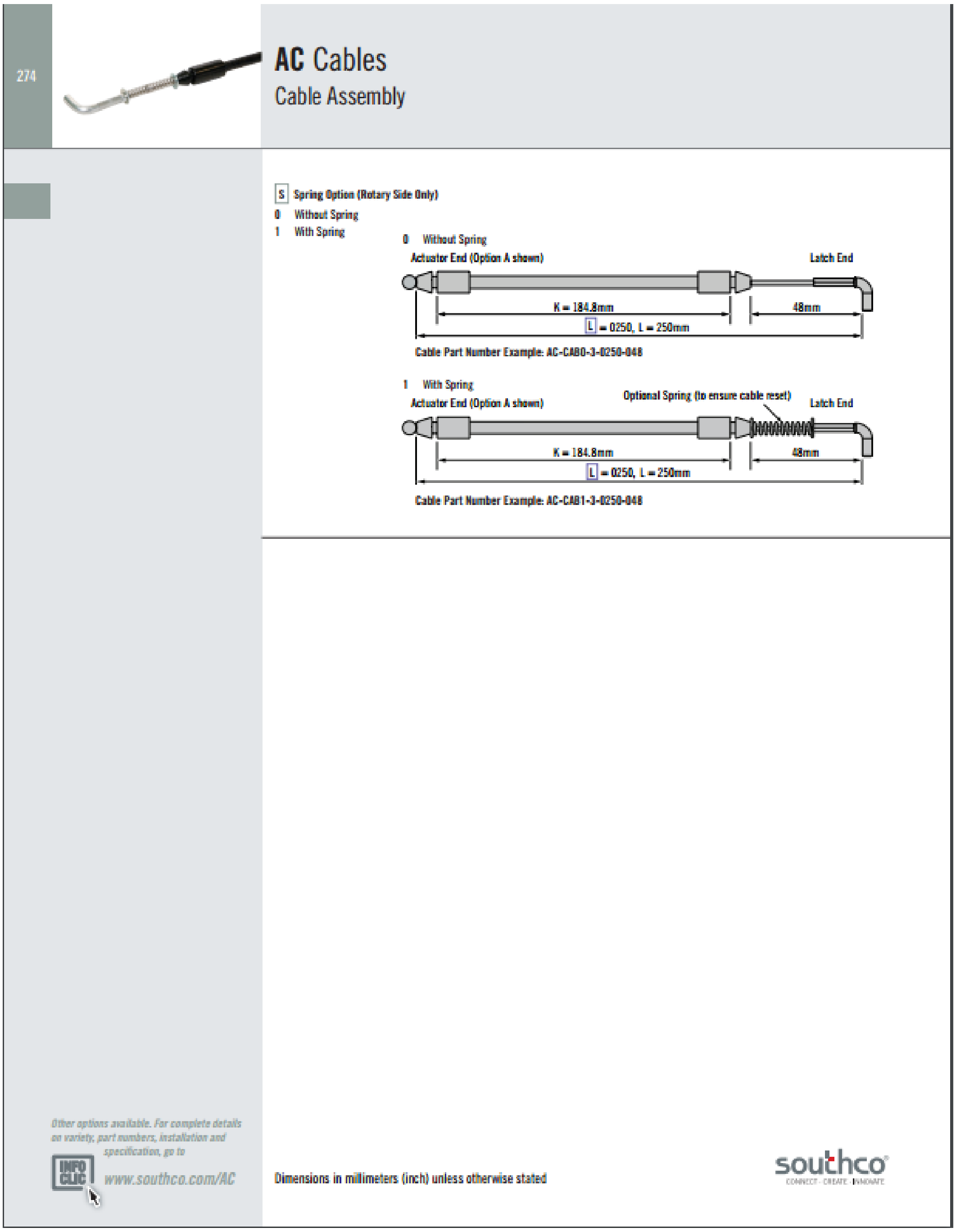
SouthCo, Push to Close Latches, retrieved 2017-04-26, from https://www.southco.com/en-us/r4-r/r4-10-20-501-10

Appendix B



SouthCo, Push to Close Latches, retrieved 2017-04-26, from https://www.southco.com/en-us/r4-r/r4-10-20-501-10

Appendix C



274

AC Cables

Cable Assembly

S Spring Option (Rotary Side Only)

0 Without Spring

1 With Spring

Cable Part Number Example: AC-CAB0-3-0250-048

Cable Part Number Example: AC-CAB1-3-0250-048

Other options available. For complete details on variety, part numbers, installation and specification, go to

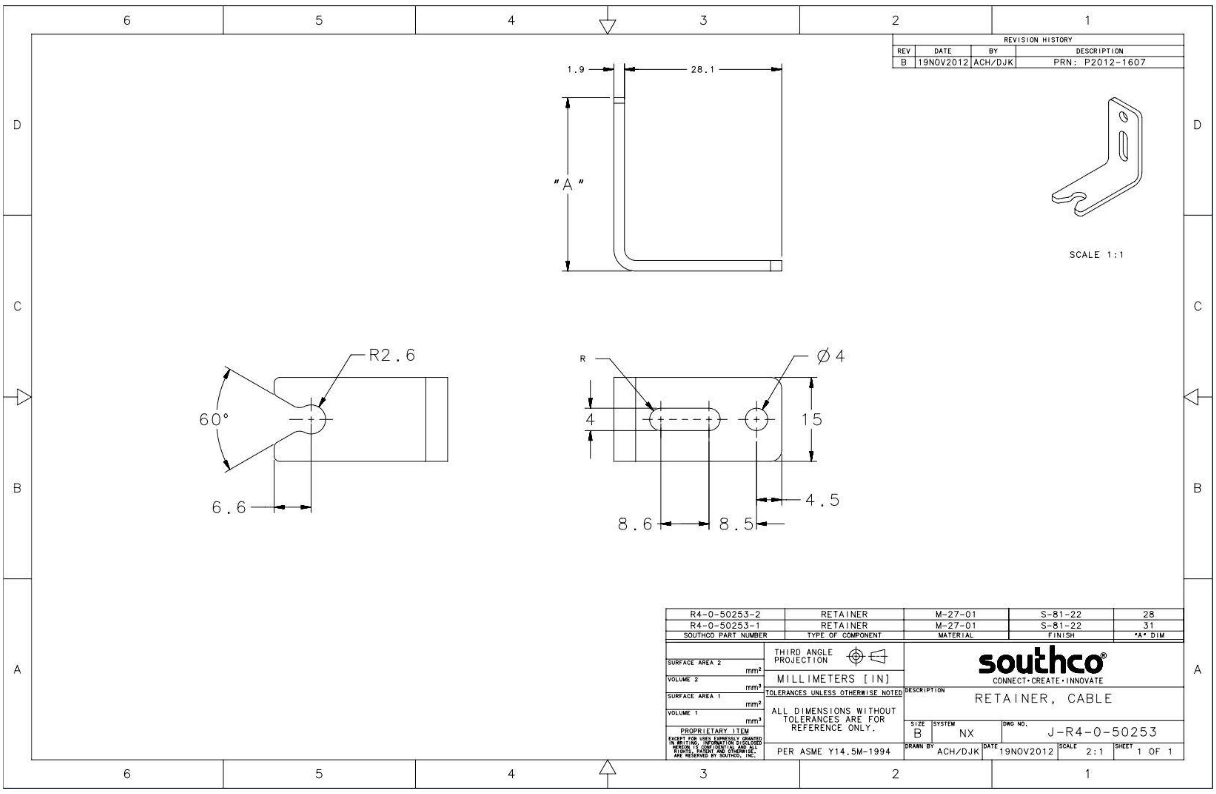
INFO CLIC *www.southco.com/AC*

Dimensions in millimeters (inch) unless otherwise stated

southco CONNECT · CREATE · INNOVATE

SouthCo, Rotary Latch Systems, retrieved 2017-04-26, from https://www.southco.com/static/Literature/AC-CA.en.pdf

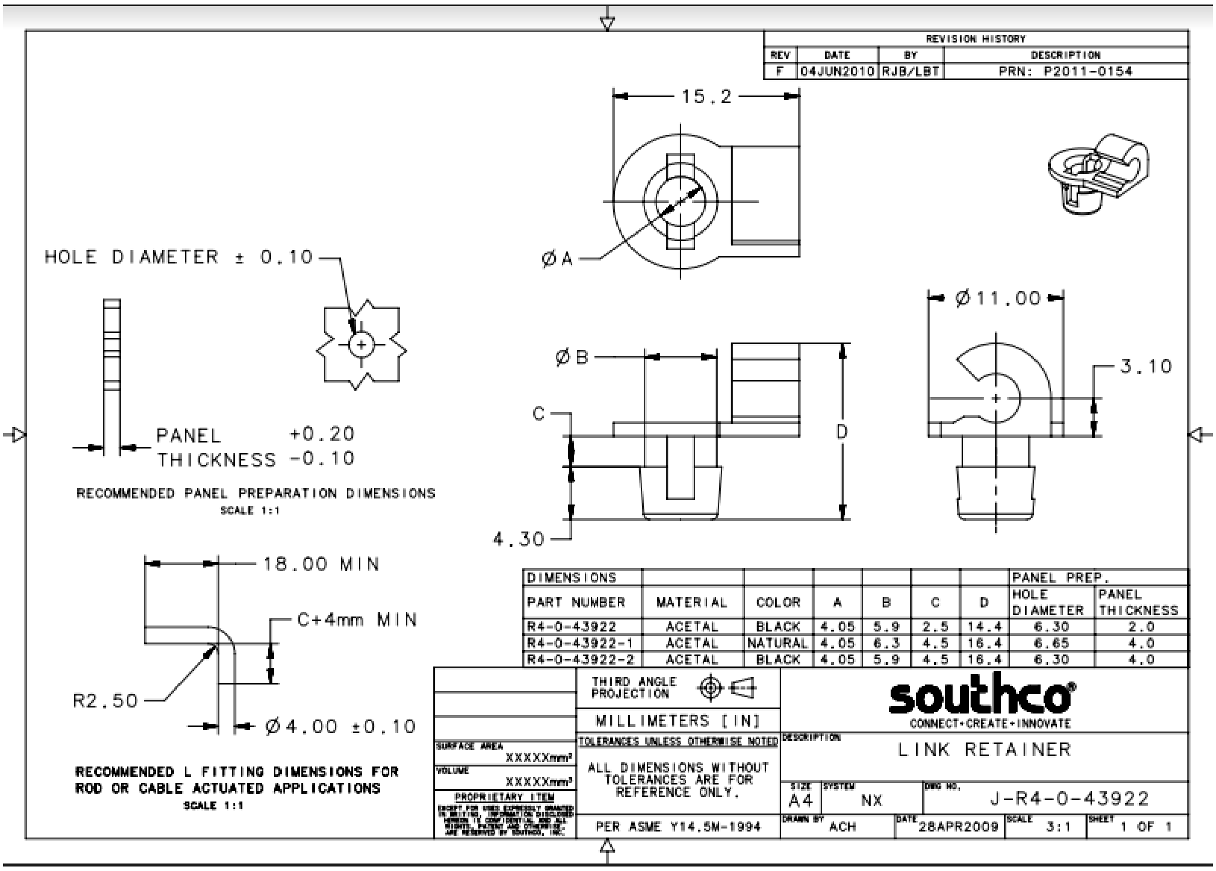
Appendix D



SouthCo, Push to Close Latches, retrieved 2017-04-26, from

https://www.southco.com/en-us/r4-r/r4-0-50253-1

Appendix E



SouthCo, Push to Close Latches, retrieved 2017-04-26, from
https://www.southco.com/en-us/r4-r/r4-0-43922