Modularisation of Cab Interior

Development of a Modular Side Console

Master of Science Thesis

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Göteborg, Sweden, 2012

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ABSTRACT

To be competitive a company has to cover as many of the customer needs represented on the market as possible. If the company are producing a number of different products the needs to cover are drastically increasing. In the case of Volvo Construction Equipment, where this thesis was carried out, this issue is solved by a great number of unique solutions for each product. With a great number of unique solutions comes increased internal cost. To reduce this cost and increase the commonality among the different products Volvo Construction Equipment are implementing more modular solutions to their products. This thesis covers the development of a modular side console for excavators, compact excavators, wheel loaders, compact wheel loader, motor graders and articulated haulers.

The thesis was carried out with a combination of the *Generic Product Development Process* and the *Product Development Funnel* with focus upon modularity and costumer needs. A comprehensive research phase was done in order to gather the knowledge about the different products and the specific needs associated with them. In order to cover all the technical requirements and to be able to modularise the solution, a *function analysis* was performed which made it possible to group different functions into modules. The conceptual modules became the base for the concept generation which later on was further developed with 3D-modeling and manufactured as a rapid prototype.

The result produced by the product developing team has managed to fulfil the requirements regarding modularity since the result can be applied in the covered vehicles. The solution can in large extent be used on both sides and together with the increased commonality the numbers of unique parts are reduced. The customer needs fulfilment has increased compared with today's solution.

Furthermore it can be said that a combination of the *Generic Product Development Process* and the *Product Development Funnel* was suitable for this thesis and combined all aspects to reach the final result was covered.

Keywords: Modularisation, Side Console, Construction Equipment, Generic Product Development Process, Product Development Funnel

ACKNOWLEDGEMENTS

There have been several different persons that have helped out with this thesis. First of all we would like to thank our supervisors; Andreas Dagman at Chalmers University of Technology and Robert Sundkvist at Volvo Construction Equipment. Their contribution to this thesis has been of great importance. They helped us to focus on the main issues and made sure that we got the help we needed.

We greatly appreciate the help we received from everybody at Cabs Technology Platform at Volvo Construction Equipment in Eskilstuna together with the product design department in Göteborg. They took their time to answer all of our questions and to participate in the meetings with us. Given that we had limited knowledge of the area before starting the thesis this help has been crucial for the results of this thesis.

During the first half of the project there were several interviews and we would like to thank everyone that participated during brakes, after work hours or during their work time. The results of the thesis would not have been possible without them.

We received great help from the people at Volvo Group Trucks Technology with the manufacturing the prototype and they gave us workspace to assemble and increase the surface finish of the design.

We appreciate that Carl Gustafsson took his time to help us to get in contact with several forest machinery operators even though he suffered from severe back pain. His contribution was important for the results of this thesis.

Final thanks to Robin Höstman and Rickard Dahl helped with proof-reading and opposition of presentation.

Gustav Andtbacka and Niklas Dyverfors
Göteborg 2012

Definitions

Below follows a short description of the different vehicles covered in the thesis as well as a description of the side console.

Excavator

Figure 1. Image of a crawler excavator (Volvo CE, 2010)

There are three different kinds of excavators; wheel-, crawler- and compact excavator. The wheel- and crawler excavator are similar to each other while the compact excavator is a simplified version with less adjustabilities and designed for other fields of application. The wheel excavator is manoeuvred with a steering wheel while the compact and crawler excavators are manoeuvred with two levers.

As seen in Figure 1 an excavator can be used for digging, however it has several other fields of application, from demolishing buildings to building golf courses. To make this possible the excavator can be equipped with several different tools and equipped with several different controls inside the cab. The implements are controlled by two hydraulic joysticks which contains several different functions.

Wheel Loader

Figure 2. Image of a wheel loader (Volvo CE, 2012a)

This vehicle comes in two types, compact wheel loader and wheel loader. The compact wheel loader is a smaller version focusing on costumers without the need of a heavy duty vehicle. The wheel loader can be manoeuvred with steering wheel or by controls that are placed on the side console. The wheel loader, see Figure 2, is mainly used for transporting goods at construction sites or refining industries. There are three different types of controls for the implements; hydraulic levers, electric levers and hydraulic joysticks.

Articulated Hauler

Figure 3. Image of two articulated haulers (Volvo CE, 2011a)

The articulated hauler is used for transporting goods, often at construction site and refining industries, see Figure 3. It is similar to a traditional truck with the main difference that it is designed for rough conditions. The cab is spacious and has few controls.

Compactor

Figure 4. Image of a compactor (Volvo CE, 2008a)

Compactors come in many different sizes. They are used for compaction of the ground either as preparation or as seen in Figure 4 for finishing the surface. The small compactors have few controls and do not have a cab, while the big compactors have a cab and more controls but still few compared to the other machines in the Volvo Construction Equipment catalogue.

Motor Grader

Figure 5. Image of a motor grader (Volvo CE, 2009a)

Motor graders are mainly used for levelling of roads but can also be used for snow removal or, see Figure 5, soil scarification. The blade under the grader can be adjusted in every possible way, which means that there are several controls inside the cab. The manoeuvring of the vehicles has a complicated system with several levers.

Controls

The definition controls are used for the following units:

Rocker Switch

Figure 6. Image of a rocker switch.

Rocker switches, see Figure 6, are the most common control in the vehicles included in this thesis and it controls several tasks. It occurs as either a two or three state switch.

Knob

Figure 7. Image of a knob

These controls are used to either switch between a number of different modes or it can be used for variable adjustments, see Figure 7.

Keypad

For these vehicles there are different keypads. The keypads have a number of membrane switches grouped together in order to create a control panel. The keypad can control other units such radio or air conditioning, see Figure 8.

Figure 8. Image of a keypad.

Manoeuvring

The definition for manoeuvring units are used for the following

Joystick

The joysticks are used for the Manoeuvring of equipment in the excavators, compact excavators, compact wheel loaders and the motor graders. An image of a joystick can be seen in Figure 9.

Figure 9. Image of a joystick in an excavator.

Lever

Figure 10. Levers in a wheel loader

The levers are used for several different tasks in the vehicles. In the excavators it is used to adjust the blade or to use the support legs. The wheel loader uses the levers to control its equipment. An image of a lever can be seen in Figure 10.

Side Console

Figure 11. Image of the inside of a wheel excavator cabin, the side consoles can be seen on both sides of the chair (Volvo CE, 2009b)

One of the things that the studied vehicles have in common is that all of them have a side console. The side console is a console which contains everything from joysticks to electric supply. The excavators, compactors and wheel loaders have most of their controls (levers, joysticks, rocker switches) on their side consoles and the consoles are mounted on both sides of the chair. The articulated hauler and motor grader have a different type of side console which is mounted on the right hand side cab wall. In these vehicles the console is used less. The different side consoles have few parts in common and are thereby unique for each type of vehicle. Figure 11 shows an image of the side consoles in a wheel excavator.

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1 INTRODUCTION

The introduction chapter will explain the scope of the master thesis; the background part will explain the history and current situation of Volvo Construction Equipment and give an introduction of the problems with commonality between the current products. The purpose, objective and delimitations will explain what the thesis will cover and why some parts are left out.

1.1 Side Console

Volvo Construction Equipment (Volvo CE) manufactures several different vehicles which all have different area of practice. All of their vehicles have a side console in common which comes in different types and layouts for the vehicles. The side console contains the manoeuvring equipment (joysticks and levers), rocker switches for everything from lights to hydraulics and knobs for speed and climate control. The side console can either be mounted on the driver seat or on the right hand side cab wall. The vehicles have their own unique solutions for the side console which also lead to low commonality between the different vehicles. A side console from a wheel loader is shown in Figure 12.

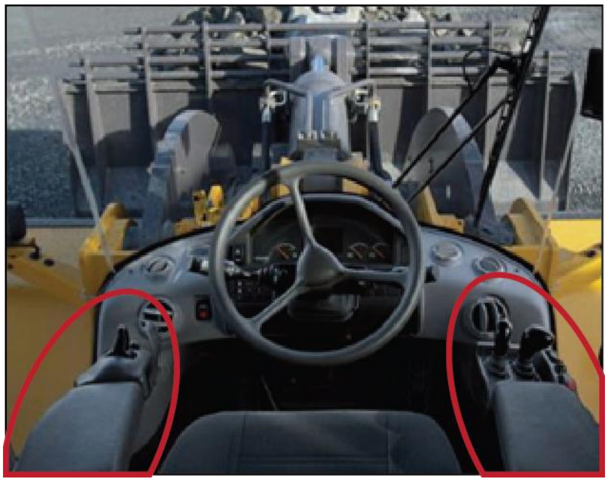


Figure 12. Side console (marked in red) in a wheel loader (Volvo CE, 2012b).

Implementing a modular solution that can be used in several of the vehicles in the Volvo CE product catalogue would mean that they could decrease the number of parts. Furthermore it would lead to a possibility to increase the product offering with a minimum of internal product variation. The side consoles used in today's vehicles are, as described above, unique for each vehicle; implementing a modular solution with standardised interfaces could lead to higher commonality and lower production cost and further possibilities for Volvo CE to offer customer specific products without having to make extensive changes.
It is not possible to modularise the consoles in today's vehicles, since they are of integrated architecture with low commonality between the vehicles. The side consoles used in today's vehicles have few things in common and new solutions have to be

developed and adapted to the needs of each vehicle. Volvo CE would like to have a modularised side console that can be implemented in as many of their vehicles as possible. If possible they would want to reuse several of the existing components to minimise the development of new components. Designing a modular side console will make it possible to achieve greater commonality between the different machines as well as decreased cost both in production and aftermarket.

1.2 Company Background

Volvo CE is part of Volvo Group which is one of the world's leading manufacturers of trucks, buses and construction equipment. Apart from these areas they also construct drive systems for marine and industrial applications and aerospace components. Volvo Group employs over 100 000 people, have production facilities in 19 countries and sales of products in more than 180 markets (Volvo Group, 2011).
Volvo CE was founded in 1832 as Eskilstuna Mekaniska Verkstad which was a local repair shop for the industries. In 1906 they developed their first vehicles that still can be found in their product catalogue as they started building road rollers and excavators. Over the years the company has developed different types of machines and it has had over forty different names. Through numerous merges and acquisitions it has become the company it is today. The merge into the Volvo brand took place in 1950 when the company was bought by Volvo Group, 1995 the company changed name to Volvo Construction Equipment. (Volvo CE, 2007)
Volvo CE has 13 000 employees, most of them are based in Europe and Asia; Figure 13 shows an overview of the Volvo CE offices and production sites. Their main markets are Europe and China and most of their customers are contractors. The main product is the excavator which stands for 36% of the sales volume, (Volvo CE, 2011b).

Figure 13. Overview of Volvo CE offices and construction plants, (Volvo CE, 2011b)

Volvo CE has a number of different products on different markets. With this comes different demands and therefore different equipment's. Today's solutions have low commonality in shared components and each vehicle has its own unique solution. Volvo CE aim to be the producer of all vehicles on a construction site, this means that they manufacture everything from motor graders to excavators, see Figure 14. This product variation leads to numerous problems such as compatibility, complexity, familiarisation, brand recognition and most of all an increase in cost for logistic and design of the different components and systems.

Figure 14. Overview of the vehicles in the Volvo CE catalogue, (Volvo CE, 2008b).

1.3 Purpose

The purpose of this thesis is to increase the commonality and product offering with a minimum of internal product variation by developing a modularised side console that can be used in the different vehicles within the Volvo CE portfolio.

1.4 Objectives

The objective of the thesis is to design a modular side console that:

- Can be used in different vehicles within the Volvo CE product portfolio.
- Is based upon a user needs study.
- Has standardised interfaces between its modules.
- Decreases the internal product variation.
- Increases the customer offering.
- Is Finite Element Analysis evaluated.
- Is ergonomically evaluated.
- Has a lower environmental impact than the current solution both when it comes to manufacturing and use.

There shall also be an economical evaluation of the concept as well as a functional prototype. The existing solutions should be reused as much as possible to minimise the cost of new component development. The new side console should be adapted for future need. This is possible through standardised interfaces which mean that new modules can be adapted to the existing interface.

2 Theoretical Framework

This chapter will explain the theory upon which the thesis is based, starting with the product development process which follows the general structure of the thesis. The modularity theory will give a general theoretical base for the concept of modularity followed by general ergonomics theory.

2.1 Product Development Process

In today's competitive market it is crucial to have a well-structured and defined product development process. Companies that in short time can deliver products that are well matched to the customer's expectations and needs will create a significant competitive leverage (Wheelwright and Clark, 1992). A product development process is a sequence of steps which transforms inputs into outputs. Many of these steps are intellectual and organisational rather than physical (Ullrich and Eppinger, 2008). Having a detailed process with well-defined steps and phases will not only make the final product better, it also enables an assurance of goal fulfilment along the process. According to Ullrich and Eppinger *op. cit.* the product development process can be divided into six key activities which are shown in Figure 15. This model is called the generic product development process. The first five phases will be covered in this thesis and explained in the following parts. The Product development funnel by Wheelwright and Clark *op. cit.* will be used as a compliment to phases two, three and four.

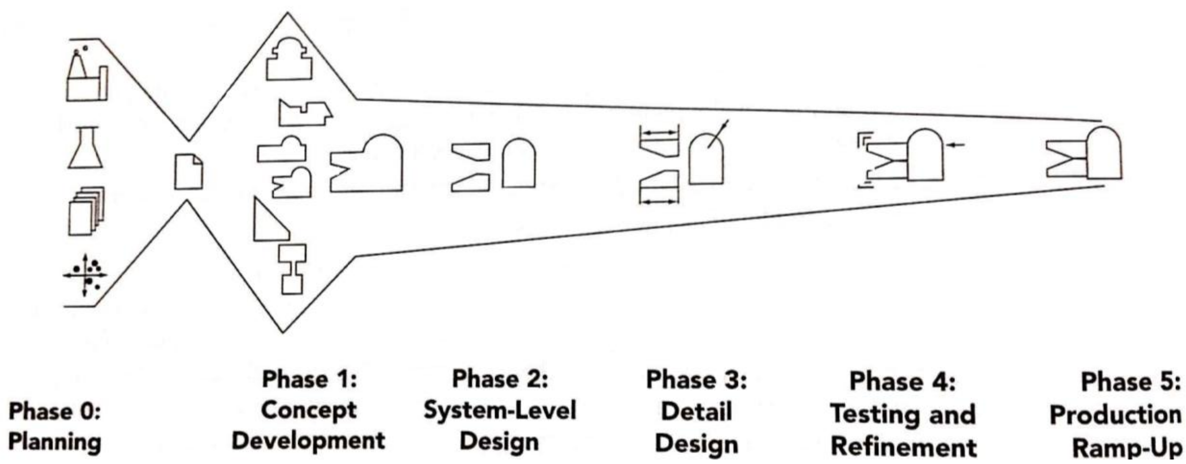


Figure 15. The generic product development process (Ullrich and Eppinger *op. cit.*).

2.1.1 Pre-study

According to Ullrich and Eppinger *op. cit.* this phase is often referred to phase zero since it precedes the project approval. This is the phase where the project is defined and planned. The stakeholders and players are identified; players are those participating in the project while stakeholders are those affected by the project. The customer should be treated as player and stakeholder which underlines the importance of involving customers in the development process (Lindstedt and Burenius, 2003).

The boundaries of the project are set by an initial investigation of the market and by defining potential market segments. This will lead to a definition of the project with project missions and a statement of who the customers are. It also declares the width of the product development process.

Gantt Chart

The Gantt chart is used to plan the project and to show the duration of the different phases in a project. Each task is represented by a straight line which length represents its duration (Johannesson et al., 2004). According to Ullrich and Eppinger *op. cit.* it is a traditional tool for planning of tasks in a project. The chart do not show dependencies between tasks which means that this is something that has to be handled within the product development team. The dependencies are only dictated by which tasks that has to be finished before others can begin (Ullrich and Eppinger *op. cit.*). As seen in Table 1 several tasks can overlap in time which means that they might be parallel, sequential or iteratively coupled.

Task 1	■					
Task 2		■				
Task 3		■	■			
Task 4			■	■		
Task 5			■	■		
Task 6					■	
Task 7					■	
Task 8	■	■	■	■	■	■
	Jan	Feb	Mar	Apr	May	Jun

Table 1. Gantt chart.

2.1.2 Research and Analysis

In the research and analysis phase the needs of the targeted market are identified. The knowledge needed for the development of the product is gathered and market research and benchmarking is made. After this phase all the information needed to develop the product will be gathered and analysed. It is of great importance to clarify the main problem at an early stage of the project according to Ullrich and Eppinger *op. cit.* The main problem should then be divided into several sub-problems that can be solved using the methods described in this chapter.

Information Gathering

An important function of market research is to understand the customer’s needs and requirements. Empirical research has shown that in most fields’ users have more to contribute to the market researcher than their unfulfilled needs. They may also be able to contribute with insight regarding solutions responsive to fulfilling their needs as well. Users has in some fields shown to be the actual developers of the most successful products commercialised by companies (Urban and von Hippel, 1988).
Urban and von Hippel *op. cit.* emphasize the importance of using what they call lead users when interviewing customers. Even though they represent a small part of the market their perceived needs can be representative for an entire market. Lead users are defined as:

- Lead users face needs that will be general in a market place, but face them long before most of the users in that market find them.
- Lead users are positioned to benefit significantly by obtaining a solution to those needs.

Gathering the information from users and customers can be done in several different ways. When gathering information from customers it is important to focus on both internal and external customers.

Interviews

Interviews can be divided into structured and semi-structured. Structured interviews generate quantitative results and were therefor not considered as an option for this thesis. When the purpose of the interviews is to gather as qualitative information as possible it is recommended to us semi-structured interviews. These interviews have an open-ended approach which is used to ensure that the interviewer can acquire the information that is consider essential, while allowing users to convey what they consider important information. This approach allows the interviewer to catch as many needs as possible, while allowing the user to talk about what they consider important. A semi structured interview allows the interviewer to ask follow up questions and to fill in gaps in the answers given (McQuarrie, 2012). At least ten interviews with lead users are needed to gather 90% of the customer needs (Griffin and Hauser, 1993).
Another method for qualitative information gathering is the use of focus groups where 8-12 users sit together with the interviewer and discusses given topics. The interviewer should act as a moderator or observer and allow the users to discuss around the topic given. It is however important that the interviewer has control over the discussion so that it stays within the given topic. The interviewer should also make sure that all members of the group get a chance to say what they think (McQuarrie *op. cit.*). Gathering 95 percent of the customer needs will require at least eight focus group interviews (Griffin and Hauser *op. cit.*).

Observations

To observe users while they use an existing product or perform a task for which a new product is required can give important information considering user needs. Observations can be passive without any interaction of how the users interact with the product. It may also involve working side by side with a customer allowing the product development team to gather first-hand experience using the product. Observations can be time consuming and if performed passively they require that the user pays no attention to the observers and performs the tasks without giving thoughts about the observer (Ullrich and Eppinger *op. cit.*).

Specification of Requirements

When the product development team consider the gathering sufficient enough they have to transform these needs into metrics which makes it possible to control if the needs are fulfilled. These needs are then transferred into a *Specification of Requirements* which is a collection of all the requirements that the product have to fulfil. A specification of requirements should include needs that the product has to fulfil as well as needs that the product development team wishes the product to fulfil. The wishes should be graded from 1-5 to declare the importance of each wish (Johannesson *op. cit.*). Requirements can be divided into:

- **User requirements:** Which are the requirements that the users have on the product.
- **Legal requirements:** Requirements set by laws and regulations.
- **Internal requirements:** Requirements set by the firm.

The specifications of requirements should be implemented at an early stage, it is however important to keep an open mind during the product development process and make necessary changes in the specification (Almefelt, 2011).

House of Quality

The *House of Quality* (HoQ) is part of *Quality Function Deployment* (QFD). It is a method used to link user needs with functional requirements, or metrics. When developing a modular product it is important to use modularity as the first and most important design requirement when using QFD; this is done to set the product development group in the correct "mind set" (Erixon, 1996). The QFD matrix is used to identify the correlation between customer demands and construction specifications. The method was developed by Shigeru Mizuno and Yoji Akao in Japan during the 1960's and has been used in the Japanese automotive industry ever since. QFD is mostly used for further development of already existing products. The method should be used as a basis of discussion in the product development team to achieve consensus of the meaning of demands and parametric values and of how they should be interpreted. The method should however not be used as a formal numeric drill, should it rather be used as a basis for discussion and documentation (Johansson *op. cit.*).

Benchmarking

To examine the relationship between the new product and competitor's products are crucial in the product development process. Benchmarking against competitors will allow the product development team to examine where they stand contra their competitors. Information on competitive products must therefore be gathered to support the decided positioning (Ullrich and Eppinger *op. cit.*).
The benchmarking should be done to evaluate possible gaps in the market and to evaluate key elements such as cost, customer satisfaction and technical aspects. During this part of the project the investment of time is essential since the information gathered is essential to the success of the project (Ullrich and Eppinger *op. cit.*).

SWOT-Analysis

The SWOT-analysis is a contraction of Strengths, Weaknesses, Opportunities and Threats-analysis. The analysis is designed to be a tool for strategic planning and to give an overview of a company's position when entering a new market or launching a new product. The fundamental part of the analysis is to compare the strengths and weaknesses of a company or product with the opportunities and threats (Piercy and Giles, 1989).

2.1.3 Concept Generation

This is the phase that Ullrich and Eppinger *op. cit.* position as Concept Development. The purpose of any product development project is to take and idea from a concept into a finished market product. A product development process starts with a broad range of inputs which gradually are refined and eliminated. This is illustrated in Figure 16 and is called the product development funnel. The funnel provides a graphic structure of generation and screening of concepts. This model is also known as survival of the fittest, where the concepts often find themselves competing with other concepts within the firm. If the products reach the market they might be competing with other products from the same firm as well (Wheelwright and Clark *op. cit.*). In this report the concepts will be considered competing with other concepts generated by the product development team.

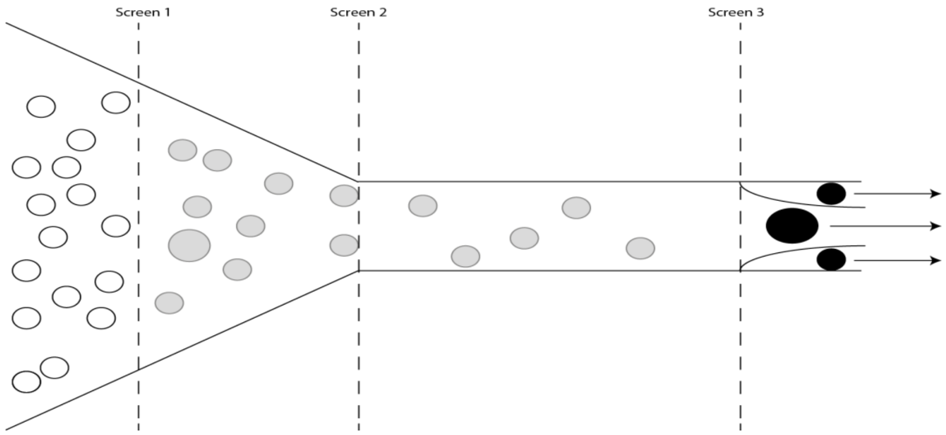


Figure 16. The product development funnel (Wheelwright and Clark *op. cit.*).

During the Research and analysis part of the project the product developers will be full of vague ideas that float around without being verified. These ideas are represented by the white circles before screen 1 in Figure 16. In the concept generation phase the circles will pass screen 1 as the team members start to focus on generating ideas based on everything that they learned in the research and analysis phase. During the concept generation phase it is important that the product developers are determined to generate the widest possible range of concepts without thinking about whether it is possible with further development or not. Only a fragment of the generated ideas might be of high quality therefore it is important to generate a substantial quantity of ideas (Liu and Bligh, 2003).

Concept Analysis

When the idea generation phase is finished the concept has to be evaluated, this is done as the project reaches screen two in the product development funnel. The first step in the concept analysis process is to eliminate bad solutions, the concepts will have to be evaluated on whether they solve the main- or sub problem, fulfil the specification of requirements, is realistic and if they are possible from an ergonomic, economic and safety perspective. The concepts will have to fulfil these aspects to pass the second funnel screen (Johannesson *op. cit.*).
The concepts that pass the second screen will then be further evaluated. The concepts are refined and some of them are merged or refined with concepts that did not pass the screen.

The third screen will eliminate the concepts until there are one or several parallel concepts that will go into final development (Johannesson *op. cit.*).

Mock - Up

A mock-up should bridge the gap between conceptual sketches and a final design. A mock-up can also cover for the different competencies and areas of interest within the team and fill an important role in the dialogue. The otherwise common issue with communicating ideas and see effects on other parts can have a tremendous decrease when presented through a mock-up (Brandt, 2007).
Brandt *ibid* means that a tangible mock-up can enhance the design process and depending on the design and level of details of the mock-up you can find different issues. This focuses the communication in such way that everyone within the product development team can contribute to the work in a more efficient way.

Concept Selection

According to Ullrich and Eppinger *op. cit.* the concept selection is an iterative process which is closely related to concept generation and concept testing. Concept screening and scoring methods will help the team to refine and evaluate the concepts and result in one or several final concepts. An illustration of the concept analysis phase is illustrated in Figure 17.

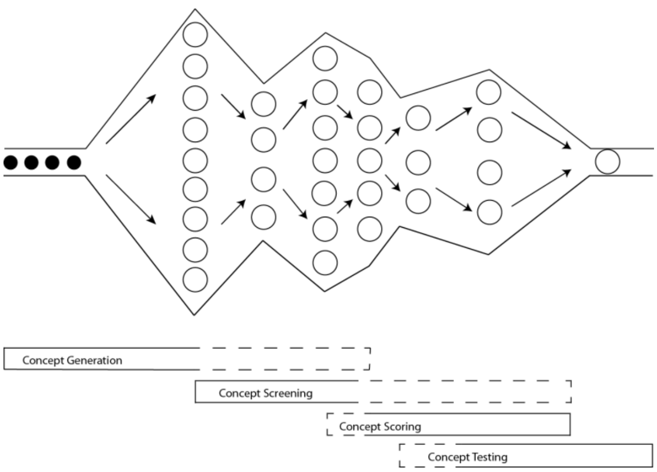


Figure 17. Concept analysis stages according to (Ullrich and Eppinger *op. cit.*).

The concept screening is done by elimination of solutions that do not fulfil the requirements set for the product; there are several methods for doing this, one being an Elimination matrix, see Appendix G. The concept scoring is done by the use of a Pugh matrix, see Appendix G. The matrixes are used to provide a neutral view of the concept selection process (Johannesson *op. cit.*).

2.1.4 Final Design

This is phase three in the generic product development process. This phase includes the complete geometry, material and tolerances of all unique parts in the product. The output from this phase is the control documentation of the product; these documents describe the geometry of each part (Wheelwright and Clark *op. cit.*).

Design

The use of computers in design is often associated with geometry modelling, animations and drawing development in CAD systems. The CAD systems allow the product development team to design the concept as close to the final product as possible, see Figure 18. Designing with shape design in a CAD program allows the designer to construct complex and free shapes. Shape design uses curves as a base and completes the surfaces by connecting different the curves created in the program (Johannesson *op. cit.*).

Figure 18. A vacuum cleaner designed in CAD (Dassault Systemes, 2012).

Material Selection

The side console will be produced in a large quantity which makes it important to find a material that can handle serial production without adding too much cost to the tooling. Material properties are affected by the manufacturing method which is dependent on the number of produced products. Different manufacturing methods put different constraints on the geometry of the product; Figure 19 shows the relationship between the factors (Johannesson *op. cit.*).

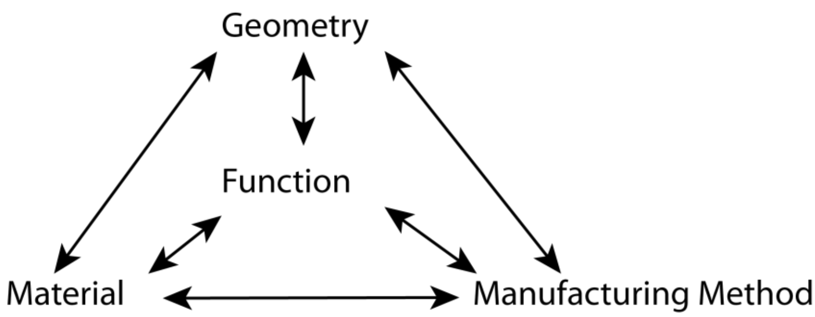


Figure 19. The relationship between material, manufacturing method and geometry. All these areas affect the function of the product (Johannesson op. cit.).

2.1.5 Evaluation

The fourth phase in the generic product development process is evaluation of the concept. According to Ullrich and Eppinger op. cit. this phase should contain reliability testing and if possible testing of prototypes. The results from the test shall then be evaluated and improvements to the design shall be done so that it fulfils the requirements for the product.

Human Mannequins for Ergonomic Simulation

The usage of a human mannequin early in the developing process can give the designer an opportunity to validate the design from an ergonomic point of view in an early state without expensive prototypes. A software generated mannequin also provides the possibility to test different sizes and gender of user and also rare body morphology types that can be hard to find in the population (Pinto and Taneja, 2005).
There are a number of different software specialised in doing ergonomic simulations. However, some CAD-software has this function as a workbench within the software itself with the benefit that the designer can see the updates immediately without exporting to different software, an example of an ergonomic simulation can be seen in Figure 20.

Figure 20. Usage of human mannequin in ergonomics simulation (Dassault Systemes, 2012).

Finite Element Analysis

The purpose a Finite Element Analysis (FEA) is to give the product developer sufficient knowledge about the strength and weak spots of a design. This knowledge can be gained in two ways:

- Producing a prototype that goes through a process of physically testing the strength.
- Perform a FEA simulation.

According to Eckard (2010) is FEA, compared with performing physical testing, a much more time and cost efficient alternative. Within product development it is a great advantage to gain this knowledge about the product as early as possible in the process to be able to perform necessary changes to the design. A FEA simulation also provides a much more detailed result with possibilities to study the performance of the design in detailed, an example of a FEA analysis can be seen in Figure 21. Eckard *ibid* also points out that the designer can gain a deeper understanding rather than just see the overall performance if he/she performs the simulation itself.

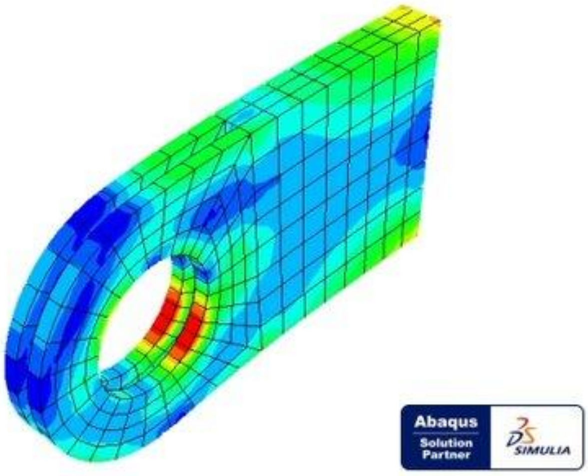


Figure 21. FEA analysis (Dassault Systemes 2012).

Rapid Prototyping

With rapid prototyping comes the great advantage that with a relatively easy and time efficient process a designer can produce a physical model of the design that can be used for visualisation, function testing and with today's technologies even go through strength testing.

According to Pham and Gault. (1999), rapid prototyping can be divided into two different groups, *Material Adding* and *Material Removal* techniques, see Figure 22. Due to the type of parts included in this thesis the *Material Removal* technique has not been included in the scope. Pham and Gault op. cit. also states that within the *Material Adding* technique there is two types of manufacturing; either it can be based upon a solid material (often a powder) or a liquid. The major difference between them is that the method based on a solid results in a prototype with great strength properties but with poor surface finish while the liquid base method is the opposite. The methods provided by the company were *Selective Laser Sintering*, *SLS*, and *Stereo lithography*, *SLA*, and therefore the only two methods included in the scope. Both methods require a CAD-model of the part that is going to be manufactured.

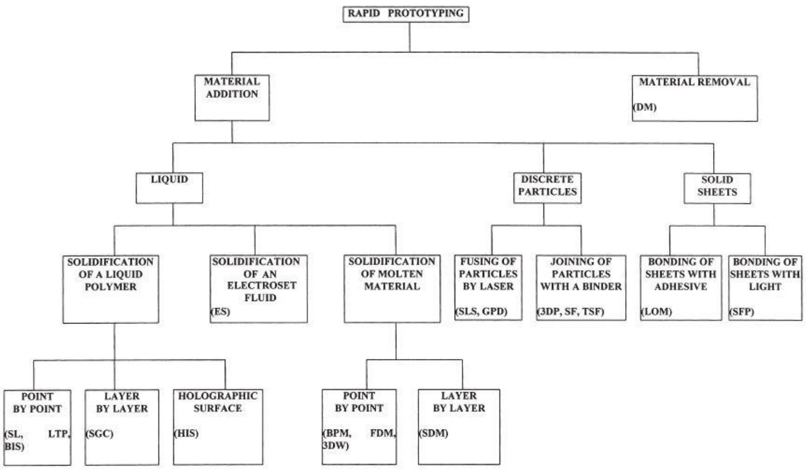


Figure 22. Types of Rapid Prototyping (Pham and Gault *op. cit.*).

Selective Laser Sintering, SLS –In this method the model is divided into microscopic cross-sections. These cross-sections are then generated, one at the time, with a laser through melting a thin layer of a polymer powder while following the pattern generated by the cross-section and at the same time joining it with the layer below. After one cycle the machine adds a new layer of material which is then melted into the following cross-section and this process repeats until the whole part is generated.
Stereo Lithography, SLA – This method work in a very similar way as the *SLS* method but with the fundamental differences that instead of adding a powder, a tank is filled with a small amount of liquid between each cycle. This liquid is than cured with an ultraviolet laser that follows the same cross-section as described in the section above.

2.2 Modularity

In today's competitive market the customer has become a powerful stakeholder. This is something that is especially noticeable in the automotive industry where a major truck developer can go a whole year without manufacturing the same truck twice (von Corswant 2011). This is done by making the products modular, which means that a module within the product can be changed without making changes to the design of the product. The customer is able to specify the product to suit their needs so that they get the product they want. This means that the companies have to focus their strategy to enhance the value of the product for the customer. To make this possible companies have to make decisions regarding the product variety, standardisation and architecture (Muffatto and Roveda, 2002).

2.2.1 Architecture

Product architecture is the scheme by which a function of a product is allocated to physical components (Ulrich, 1995). According to Ulrich *ibid* the architecture of the product is a key driver for the performance of a manufacturing firm. Having modular product architecture enables the manufacturers to change components to match the customer's needs without making complicated and costly changes in the product architecture. The opposite of a modular architecture is integral architecture; the two types of architecture are illustrated in Figure 23. The modular architecture can use the same support structure for multiple instrument panels whereas the integral architecture has to change the support when the instrument panel is changed. Product structure should however not be classified as modular and integral; modularity and integration should rather be considered as two extremes (Ulrich and Tung, 1991).

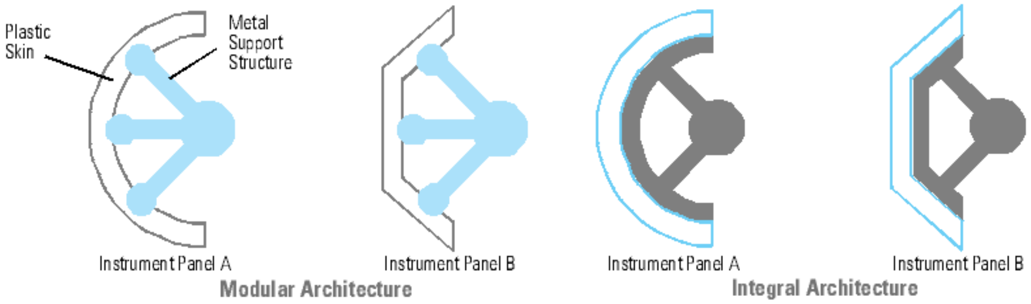


Figure 23. Modular and Integral architecture for an Instrument Panel (Robertson and Ulrich 1998).

2.2.2 Interfaces

Working with modules means that a manufacturer can build a complex product from smaller subsystems that can be designed independently while functioning together as a whole (Baldwin and Clark, 1997). Modularisation enables a maximum of product offering with minimal internal product variation. To enable the possibility to develop parts for the final product independently the interfaces between the modules has to be predefined. Predefining the interfaces makes it possible to manufacture the modular products in Figure 23 independently. According to Ulrich *op. cit.*, a module should be defined as a function carrier with a predefined interface, this is also the definition used by Volvo CE. Identifying the interfaces of a product will help to set the boundaries of the product. According to Wheatcraft (2010) it is crucial to identify the dependencies and interdependencies within the product since missing or incorrectly defined interfaces often are major causes of cost overruns and product failures. According to Miller and Elgård (1998) there are several types of interfaces, some of them are:

- **Functional**, the interface follows the allocation of functionality.
- **Mechanica**l, such as connectors, plugs or surfaces.
- **Electrical**, transferring communication, signal or power.

Interfaces can be seen as boundaries of modules facing each other or the boundary where, or across which, two or more parts interact (Wheatcraft, 2010).

2.2.3 Variety

Implementing modular architecture with standardised interfaces means that the manufacturer can deliver a wider variety of their products by changing modules. According to Miller and Elgård *op. cit.* a key element of creating useful variety is to understand the voice of the customer, the product variety has to be customer driven. In the example mentioned above about the truck developer they can offer a large variety of their products and to do so it is crucial to have well defined interfaces in their modular architecture so that components can be changed without adding unnecessary cost for both the manufacturer and the customers.
Complex products such as the once produced by Volvo CE have a few major modules that can be divided into several sub modules. One major module is the cab, whereas the side console is a sub module. However, the side console in itself can be modularised to a more extend level than it is today and it is for that purpose this thesis has taken place.

2.3 Physical and Cognitive Ergonomics

To understand the importance of ergonomics for a side console it is important to define what role the side console plays for the driver. Any type of work performed with construction equipment is the result of an interaction between a human and a machine, see Figure 24. This interaction takes place where the operator communicates with the vehicle though its controls and this is where the side console plays an important role as the link between human and machine. From a physical ergonomic point of view it has to overlap the gap between a flexible human and a static work environment. When it comes to cognitive ergonomics the side console plays the role of utilising the functions of the vehicle in a way that does not cause mental obstacles for the operator.

2.3.1 Physical Ergonomic

When a task is going to be performed with construction equipment it is organised in such a way that the driver is stationary in the cab. This is often the case in a wheel loader due to that the task of loading and unloading seldom requires any movement of the operator. However, the work task of an excavator could require that a human attend the work outside the machine but in these cases an extra person is assigned this task. This means that an operator of this equipment is more or less constantly located in the driver seat which increases the demands on the workspace and the posture of the operator.

Posture of Upper Extremities

Due to the nature of the work task, the operator has a relatively fixed posture with his/her lower body and back. Most of the movement is done by the lower arms, hands and neck. The armrest and its position play an important role for the tension in the muscles controlling these parts. According to a study performed by Feng (1997) it is possible to reduce the tension in this part significant with a lower arm support. This study investigated three types of armrest; fixed, spring-loaded and horizontal sliding, while performing four different tasks; type-writing, pipetting and two types of assembly. It is important to point out that these tasks are not manoeuvring construction equipment. However, the movement pattern is very similar to the ones from operating these types of vehicles. The result from this study showed that all three types of supports decreased the activity in lower arm, shoulder and neck muscles when performing the work tasks. To fully utilise the potential of an armrest it has to be adjusted to the user (Feng *ibid*).

Placement of Controls

Purcell (1980) emphasizes the importance of the controls as the link that communicates the thoughts of an operator as actions for the machine. The arrangement of the controls are of the same importance and according to the literature review done by Drakopoulos *et al.* (2007), the placement of controls plays a major role in the ergonomics for the workspace in a vehicle. This review was carried out on tractors. However, the workspace in tractors and construction equipment are so similar that the results are valid for this thesis as well. Not only the arrangement of the controls plays a role in the ergonomics in a workspace but also where they are located. Van Cott and Kinkade. (1972) pointed out the importance of arranging the controls in such a way that it minimises the need to change posture in order to operate a control. At the same time some placements of controls can not only cause bad movement but also be an impediment, as Hsiao *et al.* (2005) found.

With a correct arrangement and location the controls itself should follow some guidelines. For these controls Drakopoulos *op. cit.* narrows down to the following criteria.
Rocker switches:

- Width: ≥6mm
- Length: ≥12mm
- Separation: ≥19mm

Knobs:

- Diameter: 10-25mm
- Separation: ≥50mm

The keypad on the other hand has guidelines to follow as well. However, redesigning the keypad is outside the scope of this thesis and it will therefore be treated as a single unit and not as a number of push buttons. The same reasoning is valid for the joysticks and levers where there design is going to be outside the scope.

Vibrations

Today's manoeuvring system for operating the extremities of the machinery, as the bucket for the excavator, is a hydraulic solution. This means that somewhere in the system there is a pump which generates vibrations. These vibrations then propagate through the system and finally reach the operators hands as vibrations in the joysticks. Bohgard *et al.* (2009) discuss the issues that come with vibrations. These vibrations, depending on the frequency and amplitude, can have an effect on both the blood vessels and nerves of the operators hand. Even if these vibrations seams small and harmless it is a workspace related issue and can lead to injuries as *White Fingers* and *Carpal Tunnel Syndrome*.

2.3.2 Cognitive Ergonomics

How well adapted a workspace is to the cognitive ergonomics can have a great impact on the operator. Between the machine and the operator is a two way communication and in the same way as the operator needs get the information provided by the machine he/she has to be able communicate and understand the machine Bohgard *op. cit.*, see Figure 24.

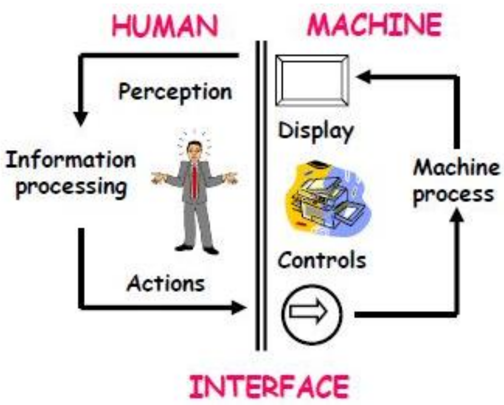


Figure 24. Human-Machine System (Bligård, 2011)

If this communication is not designed in the right way it can cause the operator not to perform at his/her best. Bohgard *op. cit.* means that the consequence from higher levels of cognitive processing in the brain will affect the operator in a way that draws the attention from an area that needs high levels of focus and brain capacity. This could be, for example, a situation in an excavator where the driver has to focus upon what the symbol of a specific control looks like instead of focusing on the precision work with lifting a heavy object. This is due to that all elements of cognition takes place in parallel and in series, so one input of information can block or delay another input. Bligård, (2011) explains solutions that could minimize this unwanted “blockage” in the information channels of the brain. These solutions focus on the arrangement and layout of control and how this could be designed in a way that decreases the cognitive processing.

- **Group** the controls based on their function or type.
- **Use color coding** in order to guide the user of the purpose of the control.
- **Use symbols** instead of text. It is important that these symbols are accepted among the specific operators.
- **Signs** that guide the user to what the control will affect

3 Methodology

This chapter will explain how the theory was applied to reach the final result. The methods together form the generic product development process. Most of the methods used to fulfill each stage are however not specified by the founders of the process, they are rather methods suited for the development of this specific product.The results are presented in the chapters 4,5,6,7 and 8.

3.1 Product Development Process

The project will follow the generic product development process (Ullrich and Eppinger 2008), see Figure 15. The generic product development process (Ullrich and Eppinger *op. cit.*). which is based on six phases:

0. **Pre-Study**: The project is defined and planned.
1. **Research and Analysis:** Gathering of customer needs and market information.
2. **Concept Generation:** The generation of concepts for the new product.
3. **Detail Design:** Design of the concept.
4. **Evaluation:** Evaluations and refinements of the design.
5. **Production ramp up:** Production of product.

The last phase as well called production ramp-is not included in the thesis. In addition to this method the product development funnel (Wheelwright and Clark 1992) will be used in phase two, three and four. This model will serve as a guide and help the product development team direct their way of thoughts as it provides a good illustration of how the concepts take shape into one final product.

3.2 Pre-study

During the pre-study phase of the project a general understanding of the problem shall be gained. This is done by in-house meetings as well as interaction with the affected vehicles.

3.2.1 Gantt Chart

The *Gantt Chart* illustrates the flow of the project and is used for planning. The chart contains several gates where various tasks have to be finalised before the gate is cleared. The chart follows the *Generic Product Development Process;* the Y-axis represents the tasks and the X-axis the timeline for the project.

3.3 Research and Analysis

This phase will cover the methods used to gather user needs and market information by interviews and observation.

3.3.1 Interviews

The aim with the interviews was to understand how the operators used the side console in the different vehicles and to gain a deeper knowledge about what could be improved from an ergonomic point of view. This knowledge is also fundamental in order to create a modular solution where the use of the different parts in the operator environment together with the functionality of the part itself is the fundamental base for clustering parts into modules. Gathering information from customers will also help in making the customer value as high as possible. To do so the focus was on lead users that could provide useful information for the development of the console, lead users will be defined in 5.1 Geographical Market Needs.

Since construction equipment are vehicles that most people do not come across on a daily basis, the purpose of the interviews was also to gain sufficient knowledge about the vehicles itself.

Structure

Initially the chosen strategy for the interviews was a semi-structure. The reason for this was to let the operator speak freely about their opinions from using the side console and driver environment of the chosen vehicle. However, after a few interviews it was clear that with a too free structure the interview tended to drift away from the subject. In most situations this is not a problem, however, the persons interviewed controls expensive equipment and occupying the operator during a longer time caused unwanted losses in the work. Therefore it was decided to make the interviews slightly less free in the structure, while still keeping them semi-structured.

Chosen vehicles

In order to gain the knowledge needed for creating a modular solution it was necessary to interview operators of different types of vehicles in order to be able to cluster functions into modules. The focus was then chosen to be upon excavators and wheel loaders. These vehicles are often used at big plants or as a part of a firm which makes it easier to find a large number of operators. They were also considered to be the limiting factors since they have the most functions mounted to the side consoles combined with the least spacious cab. It was later to be found that while performing the interviews with the operators of these vehicles articulated hauler could be included and interviewed at the same occasion since these vehicles are often located at the same sites.

The compact vehicles on the other hand are often located at rental- or smaller firms, farmers, municipalities or private persons which lead to a major problem locating the operator who is necessarily not a lead user with the opinions the interviews were aiming to find.

Motor graders and compactors were eliminated due to two reasons; first of all these vehicle could not offer much of information when it comes to the side console and operator environment because of the lack of functions in their side consoles, mostly they are not consider to be a limiting factors as the wheel loader and excavator are. Secondly, these vehicles are few to the number and they are extremely expensive to use and therefore they are occupied more or less all day which makes interviewing the operators very hard.

Interviewed stakeholders

Operators to the previously mentioned vehicles were interviewed from a number of different areas. It was decided that in order to include all the needs from the different areas where the investigated construction equipment were used it was necessary to gather the opinions from lead users representing each area. The chosen areas where:

- Alloy industry
- Gravel pit
- Construction sites
- Water, heat and broadband distributions

Workshop and aftermarket plays an important role for this project since they are the people working with customising the vehicles for the customer and mounting parts of different brands on to the vehicles. A workshop has contact with a great number of users and can be seen as a hub. Even if they sometimes spice up the stories they can provide the interviewer with the opinions from a great number of operators. Due to this they can also see trends within the market that would take a lot of time and effort to discover from just having single interviews. It was therefore decided to interview personnel at Swecon (2012) in two cities, Göteborg and Eskilstuna.

Designers of the wheel loader cab interior, *Human Machine Interface* (HMI) and styling where interviewed and frequently included in the dialog. They were of great importance when trying to understand what has been done before. A lot of important information can be gained from just understanding why some things in the past worked and some did not. The designers also provided the knowledge and reasons behind the current solution.

Laws and regulations are a major factor why a vehicle is designed the way it is. To gain this knowledge and include it in the *Specification of Requirements* a thorough study of law documents was carried out. It was later found that this area almost exclusively consists of standards, in this case ISO-standards. To narrow down the search, the department for laws and regulations at the Volvo CE provided a list of possible candidates to ISO-standards that could affect the thesis.

Study of forest machinery

During the benchmarking and interviews with operators of excavators it became clear that the forest industry had taken a quite different path in the evolution of today's operator environment. On a basic lever the excavator and the harvester do the same task but the way the machines are operated differs significantly. This was the underlying argument for spending one day in the forests surrounding Växjö talking to operators of harvesters and forwarders. The purpose was to investigate if they were pleased with the layout in today's forest machinery and their opinion of why the separation with the excavators had occurred.

3.3.2 Observations During Operation

To understand, in a deeper sense, the operator's opinions a number of video observations were also carried out.

Videos also offer a glimpse of what is going on in a cab. Apart from that it sometimes takes a while for the operator to forget that he/she is monitored observer can monitor what is going on and have the opportunity to notice things that the operator does without

knowing. For this thesis excavators and wheel loaders where studied. Video observations give the opportunity to convert the observations into metrics. However, this was not the case in this thesis because the focus was on how the controls were used and not for how long. These videos where taken in advance of this thesis and were provided by the Volvo CE.
Other observations were performed during some of the interviews.

3.3.3 Benchmarking

The market for construction equipment in Sweden is a relative small market with a limited number of actors. It was therefore decided that the benchmarking had to be comprehensive and therefore include different markets. A specific solution is often used by most or all brands within the same market segment. By extending the scope some new and innovative ideas could be discovered.
The overall focus for the thesis is upon modularity and ergonomics and therefore has the different vehicles analysed in the benchmarking been investigated according to their ergonomic and modularity performance.
The benchmarking was done by visiting those retailers that could be found within the surrounding area of Göteborg and studying folders and websites. The reason for this is that within this thesis it was not possible to buy or rent the vehicles investigated.

Ergonomics

Even if the market for the vehicles in focus for this thesis is part of a small market, there is a number of vehicles that perform very similar tasks and there is a great variety of solutions to do this. It was therefore of a great importance to gather and analyse all of these which lead to that excavators, wheel loaders, haulers, agriculture vehicles, cranes and later on also forest machinery where investigated. From the benchmarking it was clear that forest machinery did not follow the same patterns as the other vehicles. Somewhere in the “evolution” of hand controls did forest machinery take a different path apart from the rest of the investigated vehicles. After this discovery it was decided to make a visit to four of these machines and interview the operators, as were done with the construction equipment operators, in order to find out why this difference had occurred. If the root to the difference could be found it would also be possible to decide if this difference was something that could be implemented in the construction equipment segment.

Modularity

To find modular solutions that could be implemented in the Volvo CE vehicles the focus was aimed for vehicles that not necessary had all the ergonomic similarities with construction equipment. To find this, trucks and agricultural machines where benchmarked. These two markets have come a long way when it comes to modularity and the work with it has progressed for many years. The main focus was on investigating the use of common solutions and interfaces that could be adapted to construction equipment.

3.3.4 SWOT-analysis

For a SWOT-analysis to become useful for this thesis it has to focus on a new product. The result from the SWOT-analysis could then be used to focus the work on the weaker parts and highlight possible strong characteristics of the product during the concept

generation and final design. Therefore, it was decided to do the SWOT-analysis on the conceptual idea of a modular side console.
The SWOT was performed through analyse the effects that a modular side console could have in Volvo CE's product portfolio. Things that could affect the organisation itself were taken into consideration as well as how it could affect the product on the market.

3.3.5 House of Quality

This method is part of the *Quality Function Deployment* which is also known as the first house. The method allows the designer to link customer needs with construction specifications of metrics. The house of quality is based upon six different parts, see Figure 25.

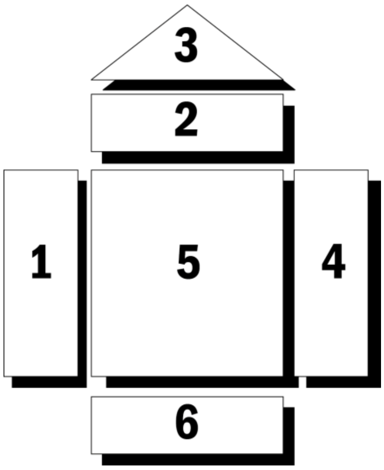


Figure 25. Illustration of a QFD matrix.

1. Customer Requirements: This part describes the various customer needs gathered during the research and analysis phase. The user needs are listed and a weight factor based upon the voice of the customer is implemented.
2. Technical Requirements: This is where the solutions are presented, the answer to how is this done? This is done via the construction specifications and metrics.
3. Interrelationship Matrix: The top part of the house explains the correlation between the technical requirements. A plus sign indicates a positive correlation and a minus sign a negative correlation.
4. Customer Requirements Benchmarking: The competitors together with the firm making the analysis are scored from one to five to show gaps in the market and illustrate the parts in which the company have the upper or lower hand.
5. Correlation Matrix: This part explains the interrelationship between the customer requirements and the technical requirements. The interrelationship is graded from strong, moderate to weak.
6. Technical Requirements Benchmarking: The competitors together with the firm making the analysis are scored from one to five to show gaps in the market and illustrate the parts in which the company have the upper or lower hand.

The House of quality show both how well the customer requirements are met and how the various technical requirements affect each other. The method was used as a support for discussions and documentation. The benchmarking against the technical requirements was not included in this thesis since it was difficult to specify metrics for the customer requirements.

3.3.6 Function Analysis

The existing side console has several different functions implemented. To be able to use as many of the existing functions as possible a function analysis had to be made. The result from the analysis is a function structure where the side consoles function coupling is shown together with its sub functions. The purpose with the analysis is to divide the problem into several sub problems, or modules, that can be solved during the concept generation phase. The analysis makes the product seem less complex and enables for the team to see potential modules (Johannesson *op. cit.*).

3.4 Concept Generation

The concept generation phase consists of both the generation of ideas for the final design as well as the selection of the final design.

3.4.1 Idea Generation

Lead users were used as support when generating new concepts to allow the user to be part of the creative process and give their inputs on what they consider important. Experts from Swecon helped with information on what they want from a new product, both from a service and seller point of view. The benchmarking provided useful input since it allowed the team to see alternative solutions both from the construction equipment market as well as other markets. Several different methods of concept generation were used in the thesis and they are described below. Figure 26 is an illustration of the result from a concept generation.

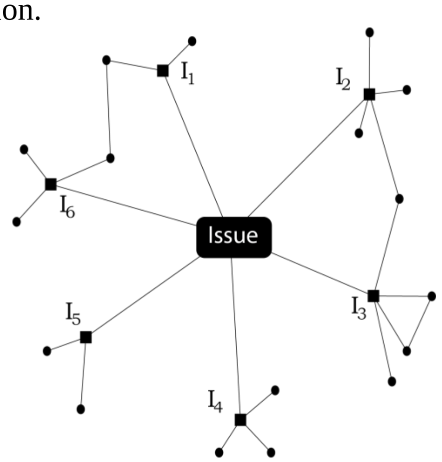


Figure 26. Result from concept generation.

Brainstorming

The brainstorming sessions starts long before the actual session. When meeting up for a brainstorming session the participants are told to first think of ideas that they can bring to the session. The session should not be longer than 45-60 minutes and all ideas should be presented. Criticism is not allowed during brainstorming as each member present their ideas. The ideas can be in the form of sketches or words. The goal with the session should be to present as many ideas as possible and to allow each members to present their ideas without anyone in the group criticising them (Johannesson *op. cit*).

Relay Baton

This method is similar to the traditional brainstorming; the product development team comes up with their own ideas and put them on paper as sketches. After putting the initial idea on paper the idea is passed on to the next member of the team who then puts his/her thoughts to the idea. The ideas should not be explained other then by the sketches and this is a way of challenging the group to further develop other participant's ideas (Michanek and Breiler, 2004).

Profiles

The product developers agrees on a famous person and starts to brainstorm how this person would solve the problem. The famous person can be everything from a movie star to a president. The only thing that is important is that everyone knows who the person is and by that can visualise how that person would solve the problem. When the product developers have come up with as many ideas as possible they switch person (Michanek and Breiler *op. cit.*).

Objects

An alternative version of *Profiles* is called *Objects*. The product developers agree on an object instead of a person. This method is recommended to use when the participants feel that they do not have any more ideas. Using objects as a reference will lead to alternative ways of thinking (Michanek and Breiler *op. cit.*).

Problem decomposition

The problem is decomposition into several smaller parts which then can be discussed and explored within the product development team. This is preferably done on a big paper or white board since it gives a good overview of the whole product. It is however important for most of all to focus on each part individually. This method can be useful when developing several independent modules (Michanek and Breiler *op. cit.*).

Morphologic matrix

The problem is divided into sub problems just as it is in the problem decomposition method. Each problem is then written on a row in a matrix. The product developers will then start generate solutions to each problem. When the developers have come up with as many solutions as possible they start to combine the problems from each row so that they form concepts that solve the main problem (Johannesson *op. cit.*).

3.4.2 Concept Analysis

After the concept generation there were several ideas of various qualities. Some of them might be discarded right away since they are unrealistic or to similar to each other. Others only solve a part of the problem and will have to be combined with other concepts to become a solution to the main problem. The concept analysis stage eliminated the concepts until there was one final solution. Two different matrixes were used in this phase; the *Elimination Matrix* and the *Pugh Matrix*.

Mock-up

In most design projects, a mock-up could offer an extra level of understanding the problem and communicate the ideas and solution of different concepts. However, for this thesis with modularity as the main requirement a physical mock-up was not the only option. For that reason it was decided that the gap between sketches and final design could be bridged in a more time efficient way with digital illustrations. These illustrations could be adapted in the same way as a mock-up in order to communicate different configurations, designs or issues.

Elimination Matrix

This is the first step in the concept selection phase. All concepts have to pass the *Elimination Matrix* to go further in the process. The concepts were evaluated on whether they:

- Solve the main problem.
- Fulfil all the requirements.
- Is realisable.
- Are possible from and ergonomic, economic and safety perspective.

The concepts had to pass all of the criteria's above to pass the matrix. Some of the concepts might be able to pass the stage with some further development or information, an example of the matrix is given in Table 2.

Elimination matrix					**Elimination Criteria** (+) Yes (-) No (?) More information is needed **Decision** (+) Pass this stage (-) Eliminated concept (?) Find more information	
Solution	**Solves the main problem**	**Fulfills all the requirements**	**Ergonomic and Safe**	**Economically realisable**	**Comment**	**Decision**
1	+	+	-			-
2	+	+	+	+		+
3	-					-
4	?	+	+	+		?
5	+	+	+	+		+
6	-					-
7	+	-				-
8	+	+	+	+		+

Table 2. Elimination Matrix.

The solutions that fulfil all of the criteria will pass to the next stage while the ones that require more information will have to be further investigated.

Pugh Matrix

This is the last method in the concept analysis phase. The *Pugh Matrix* works as a decision matrix where the concepts are compared to each other. One of the concepts is put as a reference and the other concepts are then compared to this concept based on several criteria. The matrix should be made at least two times, first with the current solution as reference and the second time with the concept with the highest score from the first matrix as reference. Having the current product as reference the first time is a way to evaluate the new concepts compared to it. It is also possible to use a weight factor for the criteria since some of the criteria might be considered more important than others. The criteria should be taken from the *Specification of Requirements* and contain demands and wishes, an example of the *Pugh Matrix* is shown in Table 3.

Criteria	**Weight**	**Alternative**			
			1	2	3
Wish D	5	**R**	0	+	-
Wish G	3	**E**	+	+	-
Demand A	3	**F**	-	+	-
Wish B	2	**E**	+	+	+
Demand B	3	**R**	+	-	+
Demand E	5	**E**	+	0	0
Wish A	1	**N**	-	-	+
Demand E	3	**C**	0	+	-
Wish C	4	**E**	+	+	-
Sum +			17	20	6
Sum 0			2	1	1
Sum -			4	4	18
Sum			13	16	-12
Furher Development		No	No	Yes	No

Table 3. Pugh Matrix with weight criteria.

3.5 Final Design

These are the methods used for the final design followed by a short description.

3.5.1 Computer Aided Design

Catia V5 by Dassault Systemes was chosen for the *Computer Aided Design*. The reasons for this were; Volvo CE works with *Catia V5* which means all the reference material provided from them has the same format. However, it is not a major issue with today's technology to convert formats between two software but it makes the process more efficient. Secondly, *Catia V5* is a software that covers all the needs for the work performed in this thesis regarding the design of the final concept.

Within *Catia V5* the workbench *Generative Shape Design* was used and all of the included parts in the final design were generated with surfaces. The workbench *Surface Design* was decided to be the far most suitable for the design and also the most time efficient with the best result since it allows the designer to generate more complex shapes.

The parts were generated as solids with the *Part Design* workbench. The reason for this was to be able to generate *FEA* and to manufacture a rapid prototype.

3.5.2 Material Selection

The material selection is done with the software *Cambridge Engineering Selector* (CES), this software allows the user to find a material that fulfils all of the criteria that the user sets up for the material. The selection can be done on three different levels. For this thesis it was decided to use level two which gives the user a selection of 100 materials and 109 processing methods. Increasing it into the highest level would, provide more alloys and mixtures of the materials. Deciding the specific alloy for a metal was however not considered as an important factor for the thesis (Granta, 2012a).
To keep the weight of the side console as low as possible it was decided that the most critical parts of the console were to be manufactured with a robust material while the parts that will not take as much stress would be manufactured in a lighter material. This is due to the dimensioning of the console; a heavy material for all structural parts would mean that the dimensions of the console would increase. The casings will be manufactured in a polymer since it allows a free design of the console. Other factors that will affect the material selection are the factors from the environment as well as the materials effect on the environment.

3.6 Evaluation

The chosen concept will have to be tested and refined to ensure that it fulfils the requirements set on the product. The methods below show how this can be done.

3.6.1 Usage of Human Mannequins for Ergonomic simulation

When using a human mannequin for evaluation and decision making the workbench *Human Posture Analysis* in *Catia V5* was used. The reason for this is due to the simplicity to use a workbench within the same software as was used for the detailed design and therefore speed up the process of validating the design from an ergonomic point of view. To validate the design and motivate further decisions, two mannequins were used. These were chosen in order to represent the two extreme cases of a possible operator. These where:

- 95th percentile male
- 5th percentile female

3.6.2 Finite Element Analysis

Due to the knowledge within the product development team of FEA it was decided to use the FEA-workbench in *Catia V5, Generative Structure Analysis*. The simulation was performed as a *Static Analysis* and the following settings were used:

- Global element size: 9mm.
- Sag: 0,9mm.
- Force: -1000N in z-direction at the upper surface of the side console, see Figure 27.
- Acceleration: -9,82 m/s^2

- Surface Properties: Concact Connection Property.
- Virtual Tightening Bolt Connection Property Tightening Force:
    - M6: 8500N
    - M4: 6000N
- Clamps: The model was clamped on the surface that is clamped together with the seat, seen in Figure 27.

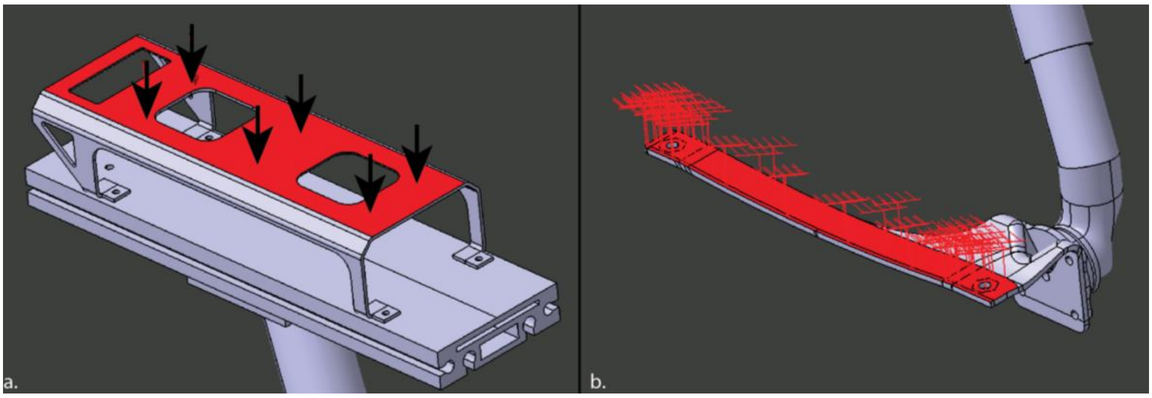


Figure 27. Force applied to the model (a), surface where the model was clamped during the FEA (b).

The purpose of the FEA-simulation is to find the maximal displacement together with locating and define the maximal stress from a simulated 1000N push on the armrest in the z-direction. To simulate this, some parts were considered redundant and not included in the simulation.

3.6.3 Rapid Prototyping

Based on the different properties associated with the two different manufacturing methods described by Pham and Gault (1999) it was decided to manufacture the prototype using *SLS* instead of *SLA*. The reason for this is that the final design was more depending on stress properties than surface finish.
The prototype was then manufactured based on the surfaces generated during the final design in *Catia V5*.

3.6.4 Environmental Aspects

CES has a function called Eco audit, this function allows the user to calculate the environmental impact caused by the product during its whole life cycle. Environmental damage is caused at four phases in the cycle illustrated in Figure 28. The results are presented in graphs and tables that allow the user to reflect on material choices and manufacturing methods which makes it possible to perform changes in order to lower the effects (Granta 2012b).

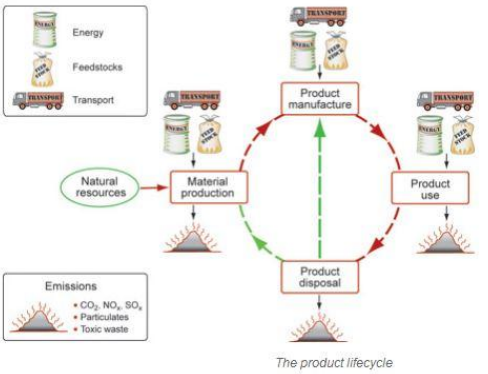


Figure 28. The environmental impact during a products lifecycle (Granta 2012b).

4 Pre-study

In this chapter the pre-study of the thesis will be explained.

At an initial stage of the thesis it is important to clarify Volvo CE's expectations. This was done to enable the planning and to clarify the scope. Volvo CE expected a modular product with standardised interfaces. The focus should be to develop a modular console with standardised interfaces and basic set modules. The interfaces should enable for Volvo CE to add more modules over time. The main focus will be upon customers acting on the Swedish market since they in most cases are the same persons as the users of the vehicles. Having the users and the owners of the machines as the same person is something that is special for the Swedish market; in most markets the vehicles are owned by a construction company. This enabled the possibility to discuss several different aspects of the console with the same persons. The final concepts shall be customer oriented, meaning that the customer's aspects of the console should be given the main focus in the development of the final concept rather than focusing on metrics. The users on the Swedish market can be considered to be lead users which will enable to cover several customer need with fewer interviews. The pre-study showed that the excavator should be considered as the limiting factor for the thesis. The excavator has more controls than the other vehicles and the cab is smaller than the others. Therefore all modules will be developed with the limitations of the excavator in mind.

It is important to gain a deep knowledge about the product and the vehicles that will be using the product. This was done by hands on testing of the vehicles and by examining the interior. A further and deeper understanding of the product and vehicles enabled for the planning of the thesis which resulted in a Gantt chart that can be found in Appendix A. The chart contains several gates and shows the deliveries for each gate.

5 Research and Analysis

The research and analysis chapter will explain the information gathering process that was done to gather the market and customer's needs to enable the development of the side console.

5.1 Geographical Market Needs

The geographical market needs will explain why the users on the Swedish market are considered to be lead users. During interviews with the workshop personnel at Swecon it became clear that almost all excavators sold in Sweden are customised before they arrive to the costumer, this was later confirmed by interviews with dealers for JCB and Hitachi. Among the things that are replaced are the joysticks and armrests. These are changed from the standard joysticks delivered with the vehicle to the most advanced joysticks on the market. At first this appeared strange since there is a huge amount of joysticks that are assembled in the factory and then changed before the vehicle arrive to the costumer. To understand this phenomena some important difference between the Swedish market and, for example, the German market has to be described.

- **German market:**
    - The vehicles on this market are owned by a number of companies. The vehicles are then operated by several different operators.
    - Each vehicle has it specific work task which means that for each job the company sends a number of vehicles of the same sort but with different equipment to do the work tasks.
- **Swedish market:**
    - A major part of this market is controlled by operators that own the vehicles they are using.
    - Each machine has to be able to perform all of the work tasks for a normal job.

These fundamental differences in the markets lead to that in order for the Swedish operator who owns his/her vehicle to be competitive; the vehicle has to be so agile that he/she can operate all the needed attachments to do the job. To do this the vehicle has to be more flexible and fitted with manoeuvring unit that can handle the demands from all the attachments.
Since the operator is the owner; they are keener to make the operator environment more ergonomic with more advanced aftermarket products than if the vehicle was owned by a company and operated by an employee.
These two reasons make the Swedish market special and considered as the most demanding market for a developer. These market differences lead to the conclusion that Swedish users could be considered as lead users.

5.2 Benchmarking

During the process both an internal and external benchmarking was performed to widen the knowledge of existing solutions. The internal was carried out first in order to learn the Volvo CE vehicles.

5.2.1 Internal Benchmarking

It is as important to search for solution outside the company as it is to benchmark the products within the company. The results from the internal benchmarking can be found in Appendix C.

Excavator: Both Excavators and Compact Excavators are included in the benchmarking.

- *Ergonomics:*
    - For the excavator and the compact excavator the ergonomic focus lies upon the manoeuvring unit (joysticks) which have a higher priority compared with the controls. This means that the only adjustability possible is to tilt the side console. The reason for this priority is that the joysticks are used continuously while most of the controls are set to one setting and then left in that state for a longer time.
    - Due to the low priority and the issue with lack of space the controls has been placed as ergonomic as possible and where the space could be found, see Figure 29. This has led to that some of the controls have been placed in areas where it causes implications to operate them, such as under the armrest, which contradicts with what Van Cott and Kinkade (1972) recommends. This is not the case for a compact excavator since it has fewer controls.
- *Modularity:* Both excavator and compact excavator have chosen to use one modular solution for the side console and that is predetermined slots where controls can be fitted if needed. If the slot is not used a casing seals the hole.

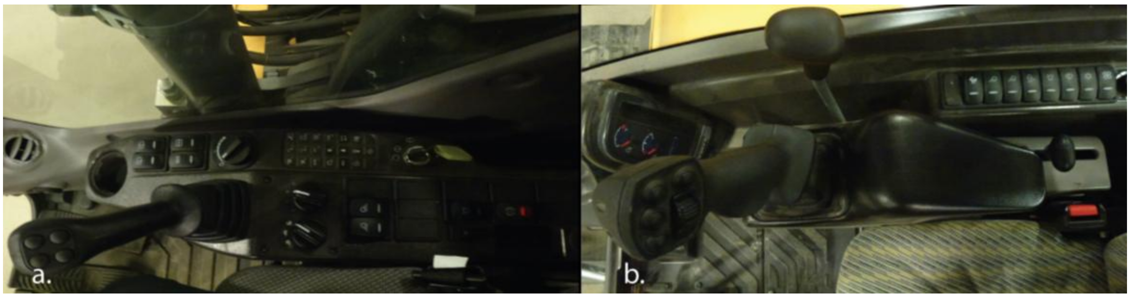


Figure 29. Side console in and exavator (a) and a compact excavator (b).

Wheel Loader: Both wheel loader and compact wheel loader are included in the benchmarking.

- *Ergonomics:*
    - The wheel loader has the best performing side console in Volvo CE product portfolio due to that it can be adjusted both length and side wise as well as

tilted. The manoeuvring unit is also attached to the same unit as the armrest which means that it follows the adjustments of the armrest, see Figure 30. A lot of this adjustability is possible due to that the wheel loader is fitted with electrical manoeuvring unit and the placement of controls.
  - The compact wheel loader however has no possibility to adjust the manoeuvring unit and the support for the hand. This is due to the usage of hydraulic levers.
  - Controls in both vehicles are mounted on the right hand side post combined with a more spacious cab, which leaves more space for the adjustability of the side console.
- *Modularity:* Wheel loaders have the same modularity as the excavators.

Figure 30. Side console in a wheel loader.

Articulated haulers: The articulated hauler was included in the benchmark even if the vehicles interior differs a lot from the rest of Volvo CE's vehicles.

- *Ergonomics:*
  - An operator of an articulated hauler uses the controls, compared with excavators and wheel loaders, less often and it has therefore got a lower priority. The main focus in a hauler lies upon the driving and the fact that the levers to control the tipping function do not need a continuous control since it has automatic tilt functions have led to its location is relatively far from the operator, see Figure 31.
- *Modularity:* The modularity in a hauler is the same as described for the excavator.

Figure 31. Side console in an articulated hauler.

Motor graders: A motor grader is a specialised vehicle with a limited area of usage which led to that there were no new ideas or solutions that could be used in this benchmarking.

5.2.2 External Benchmarking

The full external benchmarking can be found in Appendix B
As described in 3.3.3 Benchmarking, the external benchmarking was performed visually from material gathered from brochures and website catalogues from each investigated company. The benchmarking was performed with focus on ergonomic and modular solutions and also to see patterns with in each product. Therefore, the best way to present the pros and cons of each product would be to analyse them individually.

Excavators: A general conclusion for excavators is that there are very few differences between excavators of different brand both when it comes to individual solutions and when it comes to the layout of controls. Analysed brands are Hitachi, Komatsu New Holland and Kobelco.

- *Ergonomics*:
    - All brands are struggling with the same issue as Volvo CE lack of space and this causes compromises with the ergonomics due to the great number of controls that has to be fitted to excavators. Common for all brands are that they are trying hard to make it as ergonomic as possible but forced to place controls where there is space such as under the armrest. Separated controls and armrest is the solution that all the investigated excavators have chosen. Common for all brands are the usage of a side console for montage of rockers, keypads and knobs; see Figure 32. An explanation for this might be that the side consoles comes as a consequence from the usage of hydraulic components due to their weight and need to be shield of from the user.
    - The screen mounted from the factory are, if they are used, fitted to a predetermined distance to the driver in the cab, often at the right hand side, and in all cases it was just for information or it was controlled with buttons.

- *Modularity*: Among the excavators there is a relative low level of modularity. The general pattern found is the usage of a panel with prepared slots for mounting rocker switches and knobs.

Figure 32. Side console in a Kobelco excavator (Kobelco, 2009).

Wheel loaders: Compared with the excavators there is a greater variation among the different solutions used by the different brands. Analysed brands are Hitachi, New Holland and Daewoo.

- *Ergonomics:* The general layout is very similar to the excavator the only difference is that the controls have a more ergonomic placement, see Figure 33. This leads to that there is no necessary movement of the arm and hand associated with operating the controls which corresponds with Van Cott and Kinkade (1972).
- *Modularity:* Among the wheel loaders the only modular solution found was the same as among excavators.

Figure 33. Interior from a New Holland wheel loader (New Holland ,2011).

Motor grader: In the same way as described in INTERNAL BENCHMARKING, MOTOR GRADERS was it difficult to find relevant information due to that the motor grader has a very narrow area of usage and little similarities with the other vehicles. Analysed brand is New Holland.

Trucks: When benchmarking different trucks it was discovered that the environment of the operator and the work task differed too much for the ergonomics to be applicable for this thesis. They were therefore only benchmarked regarding modularity. The analysed brands are Volvo Trucks and Scania.

- *Modularity*: From standardising the size of units included in the dashboard of a truck it is possible for the investigated brands to created modules which the costumer than can place as preferred. This is something that also can be seen in the interface between the dashboard and the support of it as well. With the standardised interface it is possible to use the same support to a number of different dashboards and different models. The same philosophy is applied to left hand side drive where a right hand side dashboard can easily be adapted to a left hand side dashboard.

Tractors: Even if tractor and construction equipment has little similarities in appearance, the way the vehicles are manoeuvred and the work task has much in common. The analysed brands are Case, Fendt, JCB, John Deree, Massey Ferguson and New Holland.

- *Ergonomics:*
    - Among agricultural vehicles the variation between the different solutions are by far more extent than in any of the different vehicles mentioned earlier and it is therefore recommended that the reader reviews Appendix B. To simplify and summarise the variation it can be concluded that in a tractors the controls are of greater importance compared with construction equipment which can be explained with the way the machines work. In an excavator most of the controls are tractor has more dynamic settings and therefore the controls have a higher priority. There is also a greater variation of the controls itself used in a tractor compared with construction equipment.
    - Tractors have come a long way in developing better suited layouts of controls, from a cognitive point of view. Since the controls has higher priority the layout becomes more important compared with an excavator where the physical ergonomics of the manoeuvring modules are more important.
- *Modularity:* The modularity in tractors is low, from a visual inspection. However, it is possible that none visible parts have more modular solutions.

Cranes: Cranes has a very low level of both ergonomic and modular solutions. The remarkably low level of ergonomic solutions appears the most confusing since crane operators spend almost all the time in the cab during a work day. For this reason it was decided that the solutions used in cranes was not suitable for this thesis. The analysed brand was Potain.

Forest Machinery (Harvester and Forwarder): Forest machinery came to play a important role in understanding the evolution of today’s manoeuvring unit. This was noticed during the benchmarking and was the reason why a number of forest machinery operators were interviewed. The analysed brands are CAT, EcoLog, John Deree, Ponsse and Sampo Roesnlew.

- *Ergonomics:*
  - The layout of controls differs a lot from the layout in an excavator. In forest machinery all important and often used controls are placed on “pallets” around the joysticks that are used for manoeuvring the vehicle, see Figure 34. This solution corresponds well with the recommendations given by Van Cott and Kinkade op. cit. since it requires no extra movement of the hand to operate the controls. Some of these controls are also represented on the joystick itself with a shift-function similar to a computer keyboard. Due to the shift-function the operator can toggle between a greater numbers of functions on the joystick than there is buttons; compared with an excavator where one button has one function. This many buttons is something that contradicts with the recommendations by Bligård (2011).
  - The joysticks are smaller compared with an excavator and this is because forest machinery uses electrical joysticks instead of the hydraulic joysticks used in an excavator. This leads to smaller hand movements for the operator while operating the vehicle. The small controls combined with the small movements means that the operator controls the vehicle with the fingertips compared with the whole hand in the case of hydraulic joysticks.
- *Modularity:*
  - The forest machinery has a very low level of modularity and this can be explained by the low variation among individual vehicles. Different harvesters are often equipped with exactly the same tools and accessories and the same is valid for a forwarder.
  - In comparison with the low level of modularity it is a much higher level of commonality between harvester and forwarder both within the same brand but also between different brands. The reason for this could be that there is a small difference in work task between the two vehicles and a forwarder can be considered as a simplified version of a harvester.

Figure 34. Joysticks and “pallets” from a John Deere harvester (John Deere, 2010).

5.3 Customer Needs

It was important to start gathering the customer and user needs as early as possible. The users and customers are, as previously stated, often the same person on the Swedish market. This was of great help since it made it possible to interview both stakeholders at the same time. The study took place in Sweden 2012.This was of great importance since it allowed the team to cover a wide range of worksites on the market. The users on the Swedish market was considered to be lead users which, according to Urban and von Hippel (1988), will allow result to cover most of the customer needs with fewer interviews than what would be required in other cases.

5.3.1 Interviews

External as well as in-house interviews were carried out to ensure that as many needs as possible were covered.

Construction Equipment Operators

Most of these interviews were conducted with excavator and wheel loader operator. However, most of the operators have comprehensive knowledge regarding several different vehicles since operate more than one vehicle type. This meant that they could provide useful information regarding other vehicles as well. The interviewed operators were:

- Seven excavator operators.
- Three wheel loader operators.
- Two articulated hauler operators.

The interviews were held so that the operators could use the vehicles as mediating tools to explain their point of view. Most of the operators were unaware of the aftermarket changes which are made by the dealers. This had to be kept in mind since some of the issues discussed by the operators were third party solutions. However, it is a lot to be learned from the after-market adaptions since almost all sold vehicles are customised. most of the interviewed operators agreed upon the following:

- Symbols on the switches are easy to understand, even though most of them did not know what some of the rocker switches were used for. Most of the operators pointed out that the symbols are worn out after some time.
- Most operators said that they had to use both hands while using some functions (especially in the excavators). Most users said that they had to distract there attention in order to operate the functions and that they used few of the functions inside the vehicle.
- Some of the operators pointed out that sleeves can get caught in the rocker switches.
- The operators felt that the side console had too little adjustability. They work with a static posture and would want to be able to adjust the console in more ways.
- The original armrests are to narrow which means that the elbows do not stay in place which leads to tension in neck and shoulders.

- The controls have a reliable feeling; however, they did have concerns about the rocker switches being sensible to dust.
- They would want to have more storage space for phones and pads.
- Most of the operators were open to the use of touch screens as long as they are adapted to function in their working environment. Not being able to work because of a failure in a touch screen were a major concern.

The Excavator operators were the ones who provided most input regarding the console, most likely since they have all of their controls on it and uses it continuously. Most of the complains were unanimous among the operators, especially regarding placement of controls, some of the rocker switches are placed under the armrest which made them difficult to reach, see Figure 35. Furthermore, they complained about tension in neck and shoulders which they felt was the product of the static working posture. The excavator operator preferred to have as many functions as possible in the buttons on the joysticks. None of the interviewed operators used the standard joysticks provided by Volvo CE; neither did they know that they had aftermarket solutions. They were sceptical to the use of electric joysticks even though few of them had any experience of such use. One of the arguments for the hydraulic solutions was that it allowed the user to feel the machine working since they could feel the hydraulic oil pumping. They were also concerned that the possibility to adjust the resistance in the joysticks would be lost with the implementation of electric joysticks.

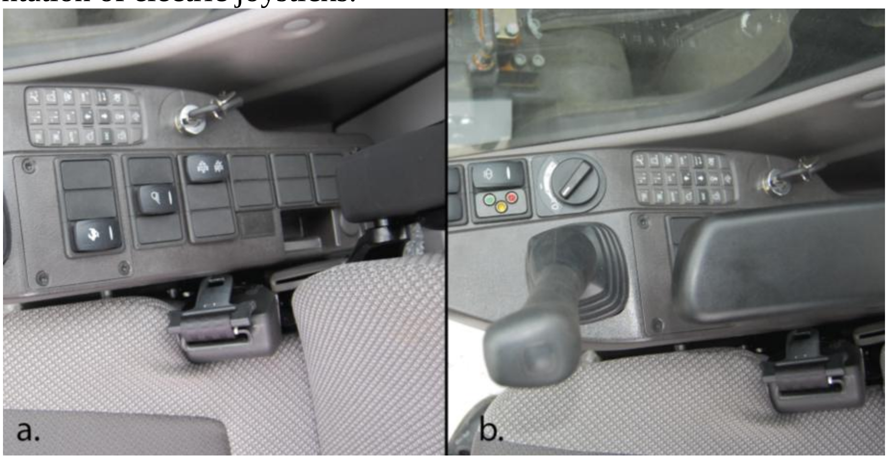


Figure 35. The side console in an excavator with the armrest folded up (a) and folded down (b).

The Wheel Loader operators preferred to use the manoeuvring units on the side console instead of the steering wheel while driving on the work sites. Some of the operators complained about the levers used to control the equipment, they felt that the levers were hard to reach and that it gave them some problem with their fingers. The possibilities for adjustments on the console was good, they did however point out that the adjustment was too complicated.

5.3.2 Observations

The observations were done both while making the interviews and by studying recordings provided by Volvo CE. A problem with the observations was that the users sometimes became too aware of the observer. It is important that the tasks are performed as they normally would, this was easier to ensure on the recordings than while riding along. However, being in the cab together with the operator enabled for the team to ask questions to the user regarding the tasks. The observations confirmed most of the information gained during the interviews. The users had to look while using the controls and in some cases found them hard to find. An interesting observation gained by observing excavator operators is that they seemed to find it hard to make precision work with the joysticks; they constantly moved their hands to new positions on the joystick to find the right feeling.

5.3.3 Aftermarket Interviews

Interviews with aftermarket companies for both Volvo CE and other brands were made.

Volvo CE

Swecon (2012) is one of the aftermarket companies in Sweden and they make almost all of the changes and services on the Volvo CE vehicles. It was therefore useful to ask them about their point of view regarding the side console and to ask them about the changes that are made to the vehicles. Three persons were interviewed at Swecon working with repairs and aftermarket adaptions, the results of these interviews are presented below.

Implementing a modular solution would make it easier to make aftermarket adaptions. It would be impossible for Volvo CE to provide all of the equipment needed on the specific markets since the vehicles have several fields of use. A modular solution would make it easier for aftermarket companies to adapt their equipment to the interfaces provided by Volvo CE. The current solutions mean that they have to make big and time consuming adaptions both to the side console but also to the equipment. The current aftermarket solutions are the same for most manufacturers, developing a modular solution might open up for Volvo CE adapted solutions.

Almost all of the joysticks in the excavators are changed before the vehicle is delivered to the customer. This is, in most cases, done without the customer asking or knowing about it. In most cases the armrests are changed, this is however something that is done after consultation with the customer. Few customers prefer the original armrests and most of them use aftermarket solutions which provide better comfort. This is however something that is special for the Swedish market. In other countries the operators will have to choose the solutions provided by Volvo CE instead of adapting the consoles to their own needs. This is because the users and customers are different people in most countries, see 5.1 Geographical Market Needs. Making changes to the factory delivered vehicles are considered to be too expensive by the owners. Implementing a modular solution with standardised interfaces would make the aftermarket adaptions less costly and by that provide the possibility for the users to affect their working environment at these markets as well.

There are some problems with the rocker switches; they have an opening under the button where dust can find its way in. This will cause malfunction in the relay and the switch will have to be changed. The workshops did however prefer the rocker switches to keypads, because if a button on a keypad stops working the whole keypad will have to be change; which is very costly and causes reactions among customers.

The people at Swecon were open to the implementation of a touch screen in the vehicles; however they were concerned with the robustness of such a screen. When asked if there is and problems with the screens that are implemented in the current vehicles they responded that they were robust enough. They said that there might be some initial resistance on the market for touch screens but that most operators would be open to the implementation providing that they had the possibility to choose whether to have the screen or not. Most users use touch screens while using other equipment such as phones and even though there might be some initial resistance they felt that the resistance against touch screens would disappear in time.

JCB and Hitachi

Interviews with two employees at JCB and Hitachi confirmed that the same aftermarket adaptions are made for other brands as well. They also confirmed that this is something that is special for the Swedish market. These brand use the same aftermarket adaptions as Volvo CE, they claim that there are few adaptions that are made to fit one specific brand. The changes are both costly and time consuming to make and as in the case with Volvo CE done without the customers knowledge. When asked why they do these changes without consulting the customer first they answered that when they deliver a vehicle with standard equipment the customer will come back to make the changes anyway.

5.3.4 Forest Machinery Interviews

There are several similarities between the usage of forest machinery and construction equipment. Yet there are differences in their side consoles, therefore it was useful to gain knowledge regarding their views of the console. Four operators of three different brands (Rottne, Valmet and John Deere) were interviewed. There were few differences between the brands regarding the side console. Rottne did however use touch screens in the vehicle while the other brands used regular screens.

Forest machinery uses electric joysticks which the users felt allowed them to relax in shoulders and neck. They could understand the initial resistance to the change into electric joysticks instead of hydraulic. However, they would not prefer anything else than electric joysticks. The joysticks allowed the operator to use small movements to manoeuvre the equipment. The joysticks used in the forest machinery have the same possibilities as the hydraulic joysticks regarding the implementation of functions meaning that they would use their joysticks for all tasks. All of the users had used hydraulic joysticks in previous vehicles.

The forest machines uses membrane buttons that are placed on large “palettes”, see Figure 36. The users felt that the functions were hard to identify at first. They did however prefer the feeling of the membrane buttons compared to rocker switches which also can be found in the forest machinery and are of the same type as in the Volvo CE vehicles.

Figure 36. Image of the buttons and the joystick in a Rottne harvester.

The Rottne users claim that their touch screens work well and they did not have any problems with quality and robustnes. There could however be problems to see the information on the screen in sunlight, this was an issue even though the screen was anti-glare treated. Even though they had the screen they could perform the same tasks with other controls as well. When asked which they preferred they answered that it depended on the task.

5.3.5 Volvo CE In-House Interviews

These interviews were done with employees at Volvo CE and done to gather further understanding of their views of the side console. The interviews provided useful information regarding what has been done in the past and what was going to be done in the future. The in-house interviews were held with key persons at different areas. The results from these interviews are presented below.

Modularity and Commonality

At the moment Volvo CE are working with the modularity of their vehicles. The current consoles are not seen as modular or communal. Inside the cab they have few modular products, this might be because the vehicles are developed and constructed in different parts of the world. Another reason is the sub-contractors that provide their solutions to the problems which are developed independently by the sub-contractors which means that Volvo CE have limited control of the solutions. The modularity and commonality issues are however regarded as important areas which has high priority in future models. One of the major concerns is to keep the number of unique components low, each item number causes costs for the company. The current consoles with its unique solutions provide several item numbers which can only be used in one specific vehicle. The variety should be customer driven and thereby allowing the customer to specify their product, similar to the solutions used in the car industry. Modularity would allow the company to provide a great amount of products on the market while in-house working with a lower amount of parts.
According to the modularity and commonality personnel the focus should be on investigating the needs from the different stakeholders in order to get a clear picture and see the pattern between models. Narrow down what is common between them and skip the parts that are not. Value the different stakeholders demand in order to solve the most critic

ones. Divide into groups of modules based upon function. Focus should be on find similarities between the vehicles and use that information to create modules. Modules can than meet the product variation demanded from the market/costumer to a lower cost. The side console should be customer needs driven, which means that the users should have big part of the development process.

Product Design

The design department emphasised that they would prefer to have a modular solution to increase the brand recognition. They did not consider that standardisation of modules was preferable, they rather emphasised the possibility to use different modularised consoles in the vehicles. They did not think that focus should be trying to find a solution that covers the needs of all the vehicles. They emphasised the importance of not to focus on the current solutions and cabs. Their opinion was that the console should be designed for future models.

Ergonomics

The future console has to be designed to fulfil the standards specified in 5.9 Laws and Regulations. Volvo CE has their own internal standard; however the focus should rather be on developing a console that fulfils the external standards and if possible make adaptions to the Volvo CE standards at a later stage. The focus should be on trying to have as few controls as possible on the left hand side console. Partly because of the placement of the door but also because they want to provide as much space as possible on the left hand side, both for visibility but also to provide a spacious feeling inside the cab.

Operator Environment

Regarding wheel loaders Volvo CE provide two types of controls, hydraulic and electrical. The electric controls stands for eighty present of the market, a future side console should be designed for these controls instead of the hydraulic which are only available on a few models. The focus should be on future models instead of the current models, the new console should show the possibilities that exist with a new console rather than being something that is adapted to what the company provides today.

5.4 SWOT – Analysis

The result from the SWOT-analysis was generated through a group discussion within the product development team regarding the potential of a modular side console. Both internal and external effects where analysed. This analysis was later used during the development process as an argument and requirement. This analysis was performed on a conceptual modular side console.

1. **Strength**
    - Number of parts: A modular solution demands lower variety among internal products which will lead to lower costs.
    - Customer satisfaction: With a modular solution the customer can specify the product more specific to his/her demands.

- Development: A modular solution makes it possible to redesign one part according to changes in customer needs without making big and costly changes to a large number of parts of the architecture.
- Problem solving: Since the linkage between different parts is reduced, solving a problem with one part becomes easier since the changes done to it does not propagate through the structure.
- Cost: The company can offer high product variation while keeping the cost of unique part numbers low.

2. **Weaknesses**
    - Knowledge: It requires that all the interacting and surrounding parts are taken into consideration; something that could lead to higher demands on the designer.
    - Compromises: A modular solution might lead to compromises regarding the different vehicles; the current solution is specifically designed for a vehicle while a module is adapted to the interfaces specified.
3. **Opportunities**
    - Simplicity: With modular solutions the product architecture becomes simpler and tasks such as service, assembly, development etc. becomes less complex.
    - Commonality: Modularity can with a bit of strategic planning increase the commonality within a company's product portfolio.
    - Brand recognition: With increasing modularity comes increasing commonality and with that comes increasing brand recognition since the number of unique designs decreases.
4. **Threats**
    - Complexity: When designing a solution that can meet the requirements from all the different modules the final product could end up being more complex than the original product.
    - Missed requirements: Since a greater number of demands and requirements are needed when designing a modular solution the risk of missing one increase.
    - Compromises: In order to accomplish the modularity compromises can be made to other important areas.

5.5 Physical Ergonomics

Since the focus of the thesis has been upon modularity there is no real stage in the process where the ergonomics has been specifically applied to the solution. During the work the physical ergonomic has been treated as a general subject with constant effect upon the work. As seen among the concepts in 6 Concept Generation and 7 Final Design none of them is a compromise of the physical ergonomics and this is the result of a constant discussion regarding whether or not the option is better or wears than the current design.

During the interviews with operators of excavators and wheel loaders is became clear that the placement of the current armrest had become better and better during the last years. According to the operators it had reached a level of comfort where the previous caused injures had decreased and starting to heal. For that reason the placement of the armrest was considered as sufficient and was therefore not changed.
Instead the physical ergonomic focused on eliminating the placement of controls that lead to extra movement of the operator in order to use the controls. An example of this is the placement of rocker switches and knobs under the armrest in the excavators. This was something that caused frustration among the interviewed operators and also later confirmed through consultation by Volvo CE.
During the same interviews it was also discovered that not all controls are continuously operated. A majority of the controls are left in one state when the operator first use the vehicle and then left in that state. However, there are a smaller number of controls that are used while operating the vehicle and therefore have a higher priority when it comes to an ergonomic point of view.
The dissatisfaction from the placement of some controls and the fact that some controls has a higher priority than other led to the fundamental statement regarding the physical ergonomics that the concepts had to fulfil; "no controls are going to be placed in such a way that it causes unwanted movement in order to operate them and if some controls are placed in a none ergonomically optimal location these are going to be controls with lower priority". When the work with concept generation and solutions to modularity this statement was slightly modified by adding; "or the operator should have the option to place the controls he/she consider has high ergonomically priority/most used in the best ergonomic position".
This statement was considered during the whole concept generation, elimination and final design in order to come up with a solution that does not cause the earlier discovered dissatisfaction among the costumers.

5.6 Examination of Modularity

An examination of the current consoles showed that they are of an integrated architecture with few exceptions. There is a possibility to argue that the excavator joysticks, which are changed in almost all Swedish vehicles, have a standardised interface. While talking about this with Swecon the technicians said that the changes that had to be made to fit the new joysticks are big and time consuming.
Some of the wheel loaders have a manoeuvring unit on both side consoles that can be resembled to a module, see Figure 37. The manoeuvring unit is separated from the rest of the console with an interface. However the manoeuvring unit is only used in some of the wheel loaders. The manoeuvring unit itself is far from modularised since all equipment on it is integrated which means that the whole unit would have to be changed if additional equipment were to be fitted. This lead to the decision that the unit was not to be considered as a module.

Figure 37. Image of the manoeuvring unit in a wheel loader.

The motor grader and articulated hauler have a side console that is integrated in the side wall of the cab. The console itself has, a somewhat, modular design where the switches and knobs are placed on steel plates that are screwed onto the console. However, to fit a new control would require to either switch the whole plate or to saw a new hole which would require a lot of work.

The rocker switches do have a more modular solution where there are many empty places for new switches and the rocker switches are mounted on a plastic plate, see Figure 38. There are snap buckles on the side of the rocker switches which makes it possible to just push the switch in place in the console, see Figure 38. There would however be a problem if the user would need more rocker switches than there are empty spaces in the console.

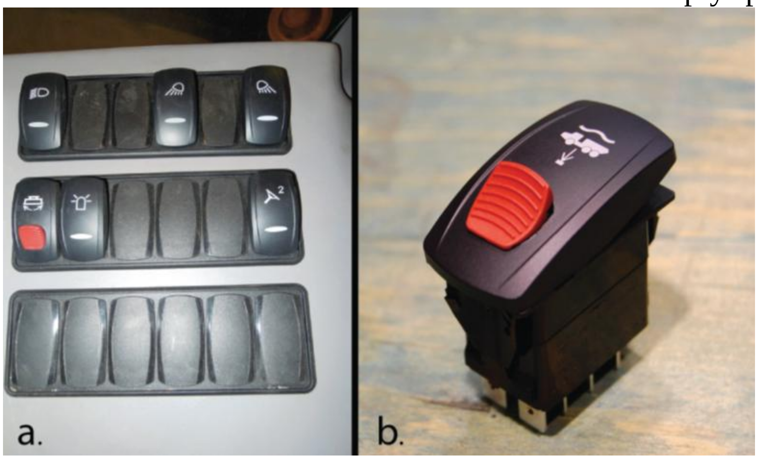


Figure 38. Rocker switch panel in a motor grader (a) and a rocker switch (b) with snap buckles on the side.

5.7 Commonality

There are few parts that are common in the side consoles among the vehicles in Volvo CE's product portfolio. They do however use the same type of rocker switches, knobs and keypads. The rocker switches are used for turning on and off functions in the vehicles. The knobs are used for selection of different settings such as four different settings for engine speed or as potentiometers. In some cases the rocker switches can work as a knob where you have three settings which the operator can choose between. These are however the only functional parts that the vehicles have in common on their side consoles. The consoles in whole are different, see Figure 39.

Figure 39. Side consoles in an articulated hauler (a), wheel loader (b) and excavator (c).

The current consoles are designed to for the purposes of the specific vehicles. This means that it would require substantial work to modularise the current consoles so that they fulfil the needs of all the other vehicles. Reusing one of the current consoles was considered to be a solution that would not be as good as it could have been. Since the current consoles have low modularity and low commonality and therefore the option of complete reuse was not considered as an option.

5.8 Function Analysis

To chart the functions in the vehicles a function analysis was made. The analysis was done by gathering the functions from the top models and specifying all of the possible functions that Volvo CE deliver, the analysis can be found in Appendix C. The top models were chosen since they are the vehicles with the most functions fitted. Some of the functions listed in the analysis are not located on the side consoles in the current models. The functions might be located on a post or at other places in the cab. However, constructing a modularised side console with standardised interfaces enables the possibility to move these function down to the console. The purpose with the analysis was to map all of the functions that could be found in the cab rather than to map the ones located on the actual side consoles considering that there is not a clear definition of what the side console is since it varies from vehicle to vehicle. This meant that there were a considerable amount of functions that had to be taken into consideration when performing the analysis. This lead to a list of functions for each vehicle which then was divided into function groups to enable the module identification. By doing so it came clear that the consoles can be divided into:

- **Manoeuvring:** A module containing the functions needed for the manoeuvring of the vehicle and some functions for the attachments, such as joysticks and levers. The manoeuvring module can vary between the right and left side console.

- **Control:** The rocker switches, keypads and knobs will be grouped into the same module.
- **Armrest:** The vehicles can be equipped with several different types and sizes of armrests. The armrests should be able to be mounted on the console with a standardised interface which would increase the commonality in the vehicles.
- **Seat:** Volvo CE has at least 20 different seats which are delivered by 10 different sub-contractors. There is low commonality between the seats which mean that there is no natural connection point that exist on all of the seats. Therefore there will have to be a seat module that can be changed to fit the different seats.
- **Electronics:** There has to be a possibility to connect 12V equipment to the vehicles.
- **Cup holder:** Replacing the current side console will mean that the cup holder is removed in some of the vehicles. Therefore there will have to be a cup holder module that can be equipped.

These modules should be regarded as main modules; there should also be a possibility to connect sub modules to the main modules.
There will have to be a base module that can carry the main modules. The base module should have standardised interfaces for connection of the modules and the base module should be the same for all vehicles while the sub modules can vary, an overview of the modules can be found in Appendix D.
The module identification lead to the decision that the concept generation phase will have to focus on concepts for the *Base* and *Control Modules*. These are the modules that are common for all of the vehicles. The *Manoeuvring Modules* will have to be adapted for each vehicle family and in some cases within the families as well. A concept generation for all of the modules will mean that the quality of the generated concepts will be low because of the limited time given to develop the side console. This means that some of the modules will be developed during the FINAL DESIGN. The interfaces for each module will however be defined so that new modules can be developed and mounted to the *Base Module*.

5.9 Laws and Regulations

The development of construction equipment is regulated by directives conducted by the EU. These laws refer to several normative ISO standards that the machines have to fulfil. Even though the EU directives only apply for Europe, by law they are applicable for the rest of the world as well. The directive that regulates the machines is called Directive 2006/42/EC on machinery. In excess to the EU directive the vehicles have to fulfil two British standards called EN474 Earth moving machinery – Safety and EN500 Mobile road construction machinery – Safety. These Laws and standards regard the whole vehicle; this chapter will only include the parts that influence the development of the side console. The ISO standards that are referenced in this chapter will not be summarised in this thesis.

5.9.1 Directive 2006/42/EC on Machinery

Regarding the ergonomics it states that under the intended conditions of use, the discomfort, fatigue and physical and psychological stress faced by the operator must be reduced to the minimum possible. This means taking to account that the side console have to be designed to fit operators of different body sizes and strength. The human - machine interface has to be adapted to the foreseeable characteristics of the operators (The European parliament and the council of the European Union, 2010).
The control units must be positioned in such way that they can be safely operated without hesitation or loss of time and without ambiguity. Furthermore, they have to be positioned in such a way that their operation cannot cause additional risk (The European parliament and the council of the European Union, 2010).

5.9.2 EN474 Earth Moving Machinery – Safety

The minimum space and location of the controls at the operator’s station shall meet the requirements specified in EN ISO 6682. A space intended for safekeeping of the operator’s manual and other instructions shall be provided near the operator’s station. The space has to be lockable, unless the operator’s station can be locked.
Earthmoving machinery shall be design according to ISO 5006 so that the operator has sufficient visibility from the operator’s station while using the machine. The test methods for the visibility shall be performed according to ISO 14401. Hydraulic pipes and hoes shall be protected so that they do not come in contact with sharp edges and positioned so that they do not cause hot surfaces. Visual inspection of hoes and fittings shall be possible. Controls shall not become warmer than 45° C during operation at an ambient temperature of 25° C.
The centreline of two adjacent controls that are intended to be finger operated should be (excluding key- and touchpads intended for fingertip activation):

- 25 mm, without divider.
- 18 mm, with divider.

Hand operated controls (with fingers around the control) should have 40 mm between their centrelines.

5.9.3 EN500 Mobile Road Construction Machinery – Safety

An electric socket intended for the connection of a lighting device for service and maintenance use shall be provided on the machine and it has to be easily accessible. The design of the socket has to prevent incorrect connection. There has to be an easily accessible storage facility for the instruction handbook (British Standard Institution, 2010).
Controls shall be designed so that they are easy to access in accordance with EN ISO 2860, EN ISO 6682 and EN ISO 3411. Furthermore, their function shall be clearly identified in the operator’s station. Machines with additional operator’s positions shall have a control system so that when one of them are used the system prevents the use of the others except for stop controls and emergency stops. The emergency stop has to be fitted in the zone of comfort specified in EN ISO 6682 (British Standard Institution, 2010).

5.9.4 Summary

To fulfil the Directive 2006/42/EC regulations the side console will be tested with computer mannequins that fulfil the ISO 6682 standards. The same standard will be used to assure that the EN474 regulations regarding the attainableness of controls are met and the EN500 regulations regarding the emergency stop. To evaluate the cognitive ergonomics of the controls a prototype has to be produced and tested on users. This is outside of the scope of the thesis; however, the cognitive ergonomics will be kept in mind while designing the console.
There is a lack of space inside the cab, especially in the excavators. In case the new side console would take up space that is used to store the instruction manual a new space for this has to be designed. Hydraulics is used in some of the vehicles; therefore, the hoes have to be protected from sharp edges and the operator has to be protected from the hydraulic hoes which can cause temperatures that exceed the limits. The side console has to be tested so that the vehicles meet the visual requirements stated in ISO 5006.

5.10 Specification of Requirements

The complete version of the *Specification of Requirements* can be found in Appendix E. The *Specification of Requirements* made it possible to refine the scope of the product and further systemise the integration of customer needs and technical requirements into the product.
Since the focus for the thesis has been upon modularity it has caused some issues with the *Specification of Requirement* due to the difficulties with translating the wishes and requirements into quantifiable metrics that could be measured and validated. However, these are the areas included in the final *Specification of Requirement*:

- Performance: Focusing on the previous solution, customer needs and commonality.
- Modularity: Treats the modularity of the product itself but also assemblies, service and adjustability for the operator.
- Ergonomics: Includes the physical and cognitive ergonomics together with the requirements and dissatisfaction discovered during the interviews.
- Material: Comprehend the requirements from both an environmental point of view but also the demands related to the environment in a cab and in close contact with a human.
- Environment: Enforce the importance of a low environmental impact.
- Design: Focusing on the general design in a cab and the importance of an esthetical appearance.
- Maintenance: Enforce the role of hygiene in a work environment.
- Production: This area place an important role for all products but especially in a thesis regarding modularity.

These areas are in most cases very subjective but, in contradiction with what Ulrich & Eppinger (2008) states, these where accepted due to that the scope of the thesis and modularity itself allows for a subjective view of the problem. The *Specification of Requirements* has focused on the customer's needs rather than internal needs at Volvo CE.

5.11 House of Quality

The house of quality was made to ensure that the main user needs would be covered in the concept generation phase. The method allowed the team to discover possible gaps in the market while comparing the user needs to the competitor solutions. One gap that was discovered was the arm/wrist support. This gap can be filled with a modular solution for the armrest which will allow the customer to equip the vehicle with an armrest that they prefer. The benchmarking against the customer needs showed that the companies follow each other which also were confirmed during the benchmarking part of the thesis. The different brands have more or less the same solutions for the issues. This could however be changed with a modular solution which allows the company to equip the vehicle with modules that fulfil the customer's needs. During the interviews it became clear that the side console would have to be flexible and follow the motion of the seat. This was confirmed by the *House of Quality* and scored with high relative weight. The *House of Quality* was used as a base for the weight criteria in the *Pugh Matrixes* in the concept generation phase. The *House of Quality* can be found in Appendix F

6 Concept Generation

The concept generation phase will cover the path from an idea to the decision of a final concept. The chapter will start with a presentation of the modules and continue with the idea generation for Base Module, Control Module and Adjustment Module. A touch screen concept will be presented at the end of the chapter.

6.1 Idea Generation

The idea generation will in most cases start as the thesis starts. It is however when the concept generation phase starts that the systematic use of methods for idea generation begins. Previous ideas should have been documented and saved for this phase. Several different methods were used for the idea generation and they can be found in 3.4.1 Idea Generation.

The identified modules for the side console are:

- **Base Module:** This is the module to which the other modules will connect; it can be seen as a main module. The *Base Module* will not carry any functions in itself it should rather be seen as the centre piece that ties the side console together and allows adjustability for the other modules.
- **Control Module:** This is the modules that will carry the controls that are needed for the vehicle. The *Control Module* should be modularised so that it can be adapted to all the vehicles without development of unnecessary unique solutions for each vehicle.
- **Manoeuvring Module:** The *Manoeuvring Module* will carry the manoeuvring equipment needed for the vehicle together with some solutions that are unique for each vehicle. There will not be any idea generation of this module since it will vary between each vehicle. There will however be a basic illustration of the module.
- **Armrest Module:** Some of the vehicles have the armrest integrated into their current side consoles while others have them as separate parts. The armrest will be considered as a module that should be integrated into the side console. There will however not be any idea generation of new armrests. The current armrests should be usable in the new side console by equipping them with a standardised interface.
- **Seat Module:** The seats have low commonality and there is no possibility to find a connection point for the side console that is common for all seats. Therefore a *Seat Module* will have to be developed; this module will vary between the different seats and machines and is meant to be the only module that cannot be used in all of the vehicles. This module will be used to connect the side console with the seat.
- **Adjustment Module:** This module is used for the adjustment of the side console. The module should be possible to manufacture in several different variants

depending on the customer's needs regarding adjustment. The module is positioned between the base module and the seat module.

- **Electronics Module:** This module will carry the electronics that is needed for the side console. The *Electronics Module* will have to carry a 12V connection for the connection of service equipment. The module should also enable the connection of any additional equipment that is used inside the vehicle.
- **Cup holder Module:** Some of the vehicles have a cup holder in their side consoles. There should therefore be a *Cup Holder Module* that can be connected to the side console or placed somewhere else in the cab.
- **Storage Module:** Many of the operators wanted additional storage. The *Storage Module* should be able to handle a cell phone and key cards. It is possible to develop additional modules for storage of pads or clothes as well, this will however not be focused upon in this thesis.

When developing a product which contains several different modules it is important to decide which module to start with. In this case it was decided to start with the base module. The *Base Module* will be the module that most of the other modules are connected to. The idea generation for this module will therefore be focused on the placement of other modules. The interfaces between the different modules will be decided at a later stage when the modules have been decided. The main focus at this stage is to decide a principal layout for the console. Even though the *Base Module* has the main focus, other modules will be generated at this stage as well. The aim for the idea generation of the *Base Module* is that all types of modules should be able to connect to it. While generating ideas the excavator was kept in mind as the limiting factor. This was done since the excavator is the vehicle that carries the most equipment, has the smallest cab and is the vehicle where the side console is used the most. Developing a modularised side console that fulfils the needs for the excavator will make it possible to use it in the other vehicles as well. The standardised interfaces will enable for other vehicle specific modules to replace the ones used for the excavator.

6.1.1 Base Module

The idea generation for the *Base Module* resulted in several different ideas which in some cases were illustrated as sketches and in others described in words. The main focus is to develop a wide range of ideas that later can be processed in the concept selection methodology. The concept generation methodology was also used to avoid any unnecessary narrowing in an early design phase and to attempt to generate novel concepts. Some of the ideas for the *Base Module* were generated together with ideas for other modules as well. This was however not considered as something that limited the idea generation. Some of the generated concepts will be presented in the following pages.

Concept Synvillan

The *Base Module* has predetermined slots where other modules are placed. It is based upon a slot principle. The *Manoeuvring Module* is placed in the left corner so that it is located as close to the operator as possible. An illustration of the right side Concept Synvillan can be found in Figure 40.

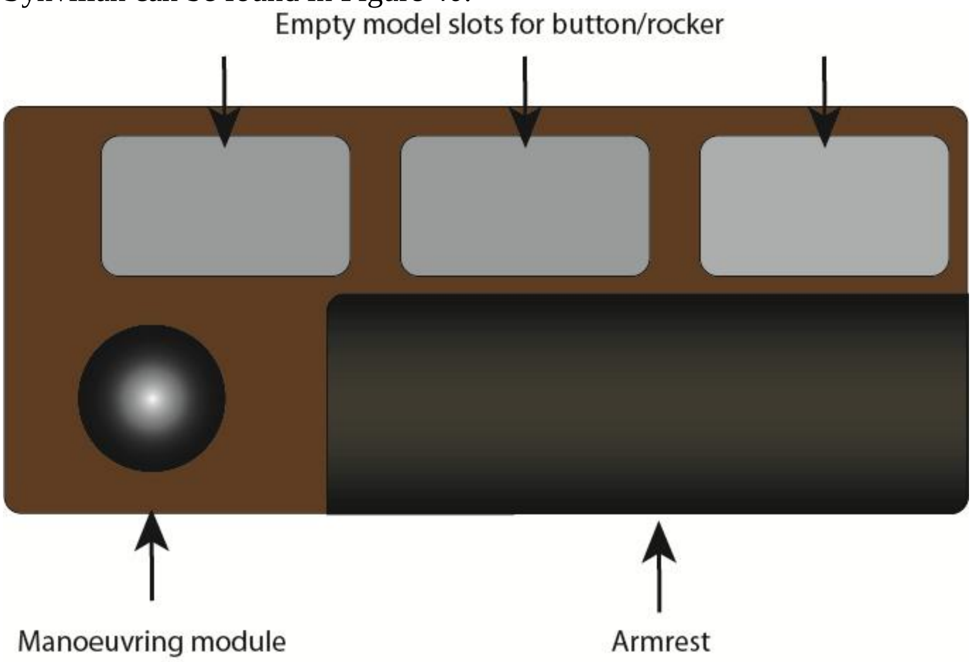


Figure 40. Concept Synvillan.

Pros:

- It has a standardised interface that can be used for several different modules.
- The empty slots do not determine where each module should be placed.
- It is possible to integrate modules on the sides of the *Base Module.*

Cons:

- It has a limited space for modules.
- The size of each module is predetermined.
- It will not be possible to make symmetric, which means that there has to be one module for the right hand side and one for the left hand side.

Concept Kopparmärra

The modules will connect to the front of the *Base Module*. The main principle with the concept is that the *Control Modules* should be moved to the front so that the operator can use them without having to turn his/her head. An illustration of the right hand side concept can be found in Figure 41.

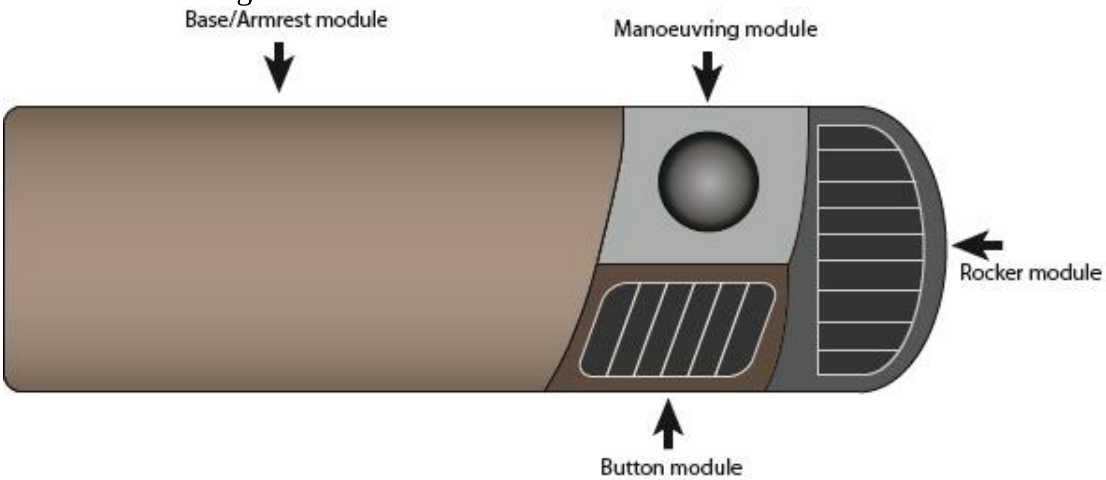


Figure 41. Concept Kopparmärra.

Pros:

- Moves the controls to a position in front of the operator which is ergonomically positive.
- Can be made symmetric.
- No predetermined places for modules.

Cons:

- Modules placed in front of the *Manoeuvring Module* can be dangerous since the operator might touch the *Manoeuvring Module* as he/she tries to reach for it.
- Placing everything in front of the armrest means that some of the modules will be placed far away from the operator.
- The *Base Module* will need to have interfaces that can connect several different modules at the same place; the other modules will also need to have interfaces that allow connection of other modules to them.

Concept Avenyn

This *Base Module* will have the *Control Modules* on the side of the module. The *Manoeuvring Module* will be placed in front of the base. An illustration of the concept can be found in Figure 42.

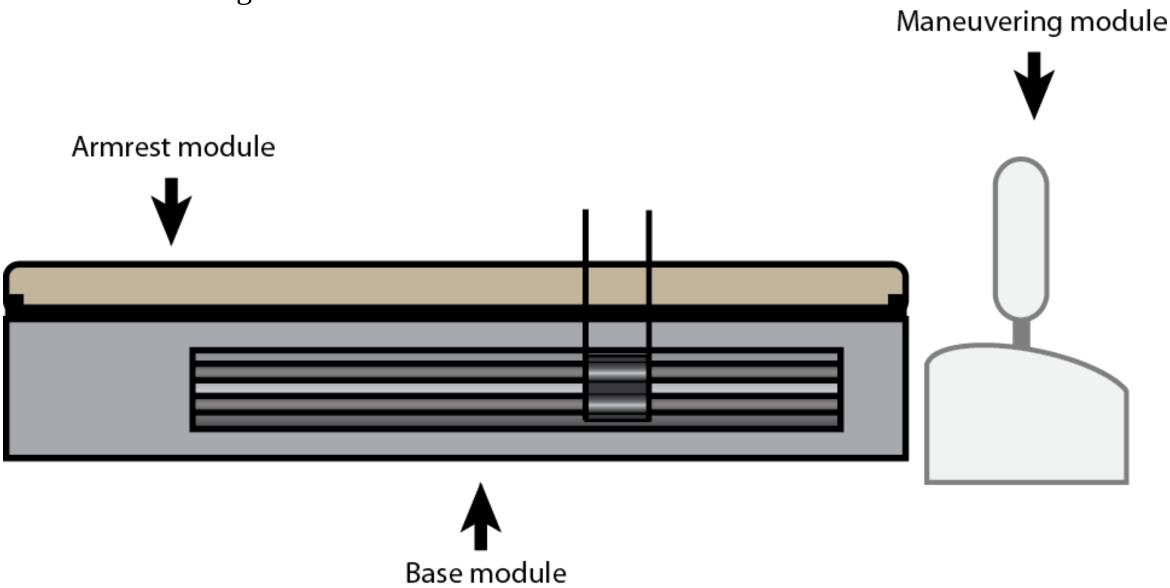


Figure 42. Concept Avenyn.

Pros:

- No predetermined size of *Control Modules*.
- Free placement of modules.
- Possibilities to use the same interfaces for several different modules.

Cons:

- *Control Modules* will be placed on the side of the console which means that the operator will have to switch focus when reaching for them.
- Placing modules on the side of the console will make it bigger.
- Limited space for additional modules.

6.1.2 Control Module

Most of the concepts generated for the *Control Module* would be possible to use with any of the *Base Module* concept. Some of the *Control Module* concepts are more adapted to the concept *Synvillan* which means that they are designed as a whole module that is positioned with snap buckles. This is however solvable by the use of casings for the module.
The main focus for the *Control Module* is adaptability; the module will have to be adaptable to the different needs of the different vehicles. The purpose with the *Control Module* idea generation was to make the controls modularised as well, meaning that the *Control Module* should be built by several different sub-modules. Some of the generated concepts are described below.

Concept Frölunda

This concept is based upon the keypads in the current side console. In the use of this concept keypads will be used for all controls instead of the rocker switches and knobs. The concept is illustrated in Figure 43.

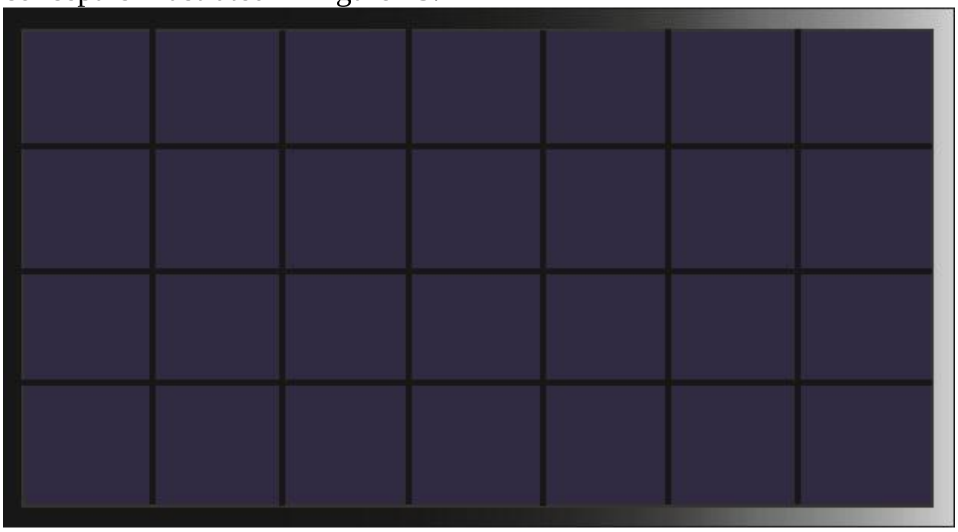


Figure 43.Concept Frölunda

Pros:

- Possibility to fit many functions on a small space.
- It is symmetric, which means that it can be used on both sides.
- Easy to clean.

Cons:

- No possibility to modularise within the module.
- If one button breaks, the whole keypad will have to be changed.
- Small buttons will make it more complicated for the user

Concept Paddan

This concept is a touch screen which allows the user to slide between different functions. The functionality reminds of touch screen cell phones where the user can find the function that he/she is looking for by sliding a finger on the display. It would be possible to design the screen so that different functions are grouped under a button, by pushing the button on the screen the sub- functions connected to that function will appear. The concept is illustrated in Figure 44.

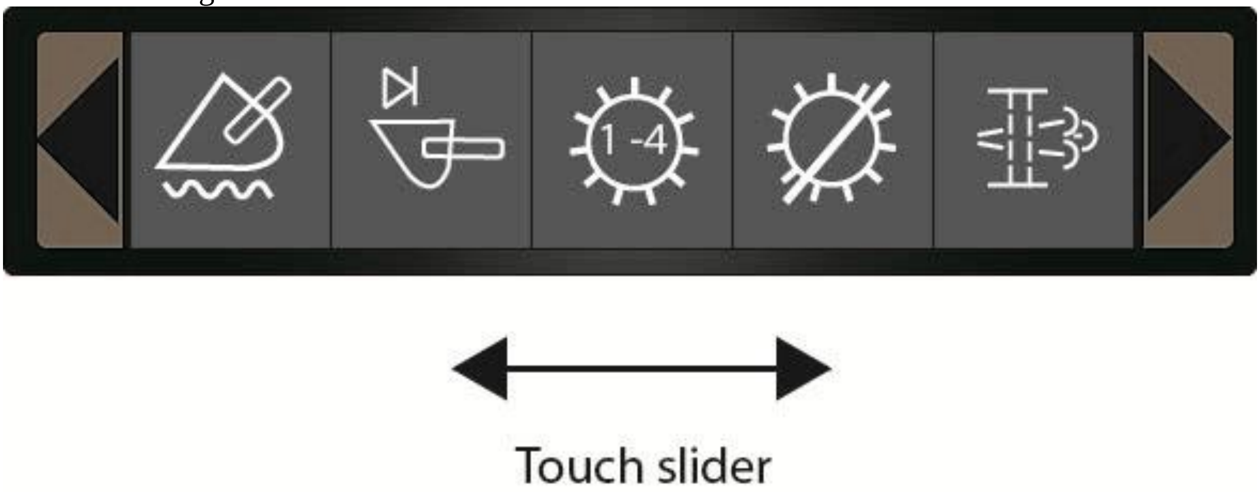


Figure 44. Concept Paddan.

Pros:

- Has high modularity which makes it easy to adapt to each vehicle and enables aftermarket adaptions.
- Will take up limited space and is symmetrical.
- Ergonomic.

Cons:

- Expensive.
- Robustness issues.
- Might be some resistance on the market for this type of solution which means that it cannot be the only *Control Module* available for the customers.

Concept Vasagrillen

This is the concept of a *Control Module* that is snapped onto a frame with snap buckles. This will enable several different *Control Module* that can be positioned in the frame. An illustration on the concept can be seen in Figure 45.

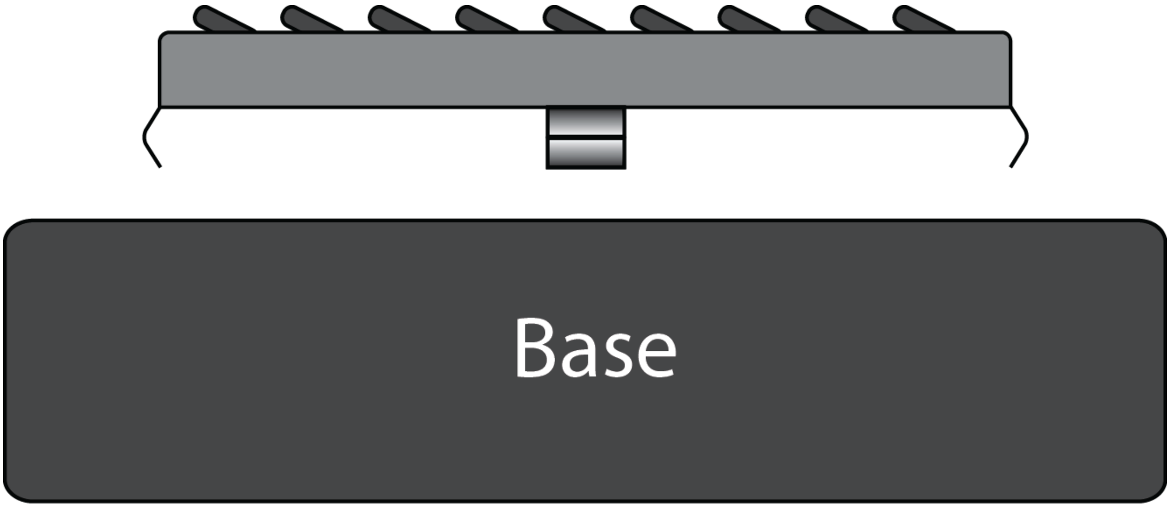


Figure 45. Concept Vasagrillen.

Pros:

- Robust.
- Easy to switch modules in case aftermarket want to make adaptions.
- Symmetric.

Cons:

- No modularity within the module, the whole module will have to be changed if aftermarket wants to add functions to it.
- Has a limitation in capacity.
- Will be hard to implement all of the controls needed.

Concept Andra Långgatan

The *Control Module* is built up by several sub-modules that connect to each other via a standardised interface. The modules should be able to use the controls that are used in the current vehicles by mounting them into casings. An illustration on the concept can be seen in Figure 46.

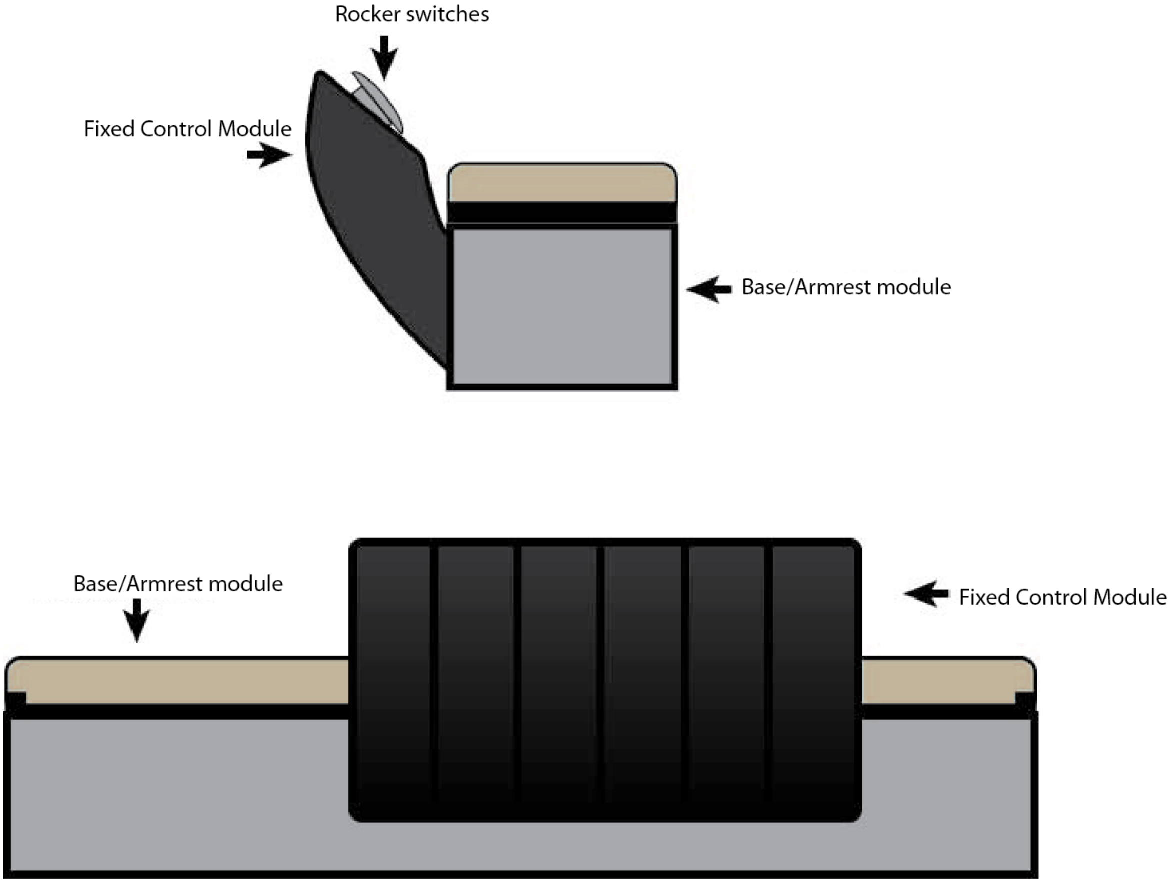


Figure 46. Concept Andra Långgatan.

Pros:

- Enables modularisation within the module.
- Enables the use of the current controls.
- Easy to make aftermarket adaptions.

Cons:

- Requires extra articles for the use of the current controls.
- Complexity.

6.1.3 Adjustment Module

Most of the concepts generated in this section are similar to each other. The adjustment and flexibility was considered as one of the most important factors by the operators. It was therefore important to find a solution that fulfilled all of the user expectations and needs regarding adjustability.

Concept Angered

This concept will allow the users to adjust the console backwards and forward as well as the height of the console. There is also a possibility to tilt the console. An illustration on the concept can be seen in Figure 47.

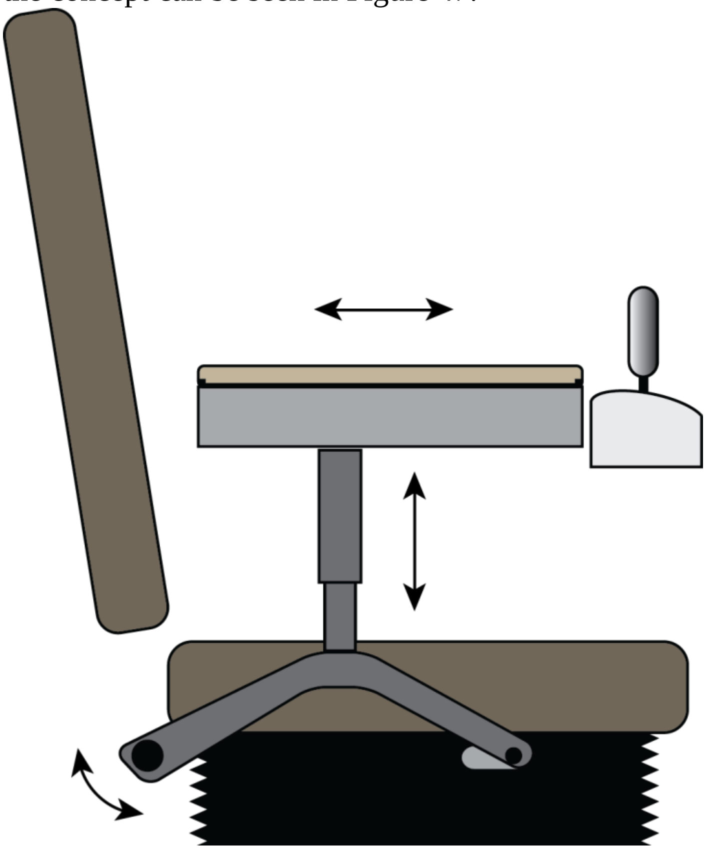


Figure 47. Concept Angered.

Pros:

- More adjustability than the current console.
- Has a spacious design.

Cons:

- Limited adjustability.
- Complex tilt function.
- No sideway adjustability.

Concept Johanneberg

This concept is similar to the *Angered* concept but by moving the support brace further backward on the console it is possible to give the side console a more spacious design. An illustration on the concept can be seen in Figure 48.

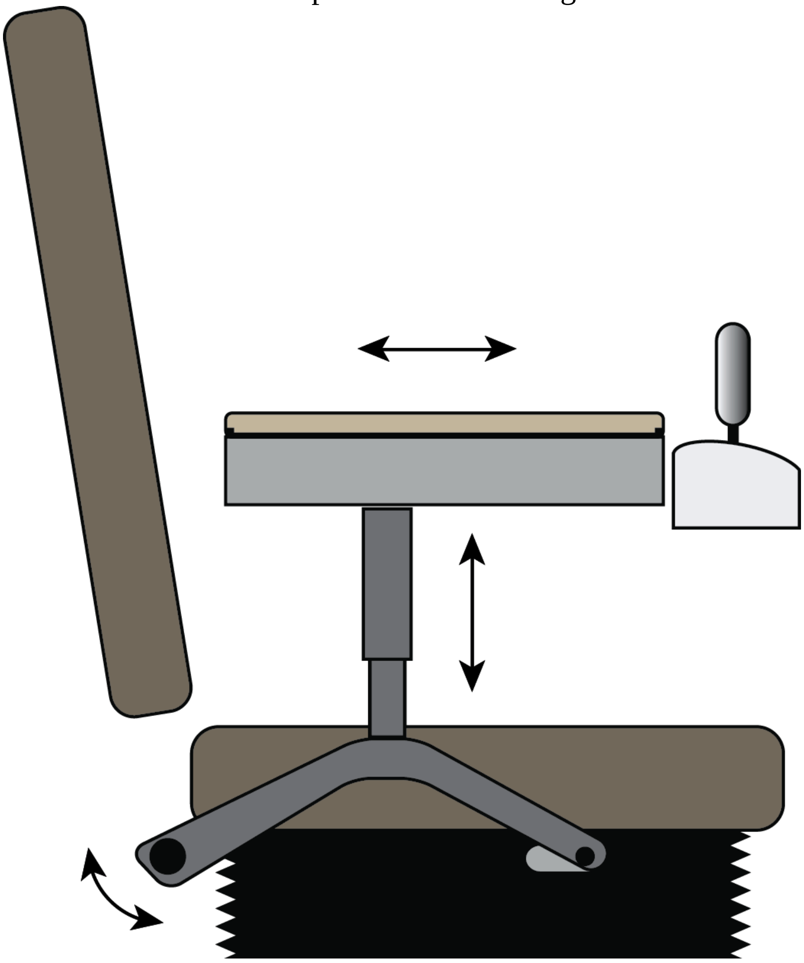


Figure 48. Concept Johanneberg.

Pros:

- More adjustability than the current console.
- Has a spacious design.

Cons:

- Issues with the robustness of the module.
- Limitations in the adjustability.
- No sideway adjustability.

Concept Olskroken

This concept allows the operator to adjust the *Side Module* in all directions. There is also a possibility to design the module so that it can be used in different price segments by locking one or several of the adjustability options. An illustration on the concept can be seen in Figure 49.

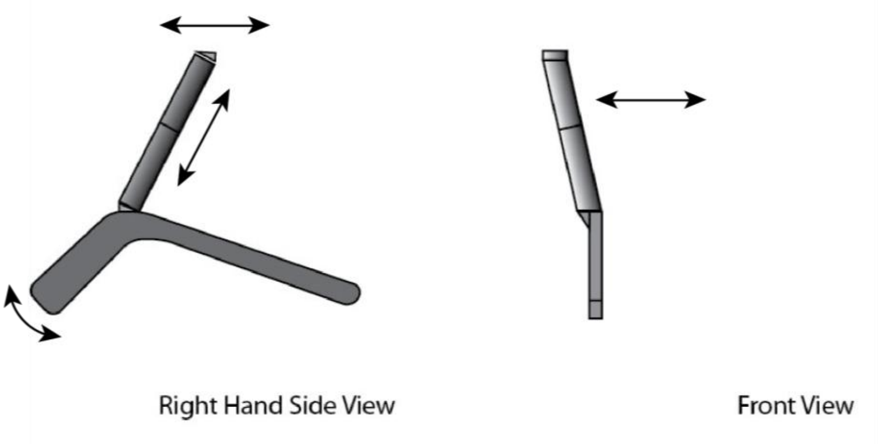


Figure 49. Concept Olskroken.

Pros:

- Enables three translation and two rotation adjustability.
- Slim design.

Cons:

- Complex adjustment.

6.2 Evaluation of Concepts

The concepts were evaluated in elimination matrixes for each module, which can be found in Appendix G. The concepts were evaluated from the criteria stated by Johannesson *et al.* (2004):

- Does the concept solve the main problem?
- Does it fulfil all the criteria in the *Specification of Requirements*?
- Is the concept ergonomic and safe?
- Will the concept be economically realisable?

In order for the concepts to pass the elimination matrix they would have to pass all of the criteria. The concepts that passed this screen would be evaluated in a *Pugh Matrix* where they were compared to the current side console in an excavator. The concepts that had the highest score in the first *Pugh Matrixes* were then to be examined in a second matrix where one of the new concepts were set as a reference, the *Pugh Matrixes* can be found in Appendix G

6.3 Final Concepts

The final concepts are:

- Avenyn, *base module*.
- Andra Långgatan, *control module*.
- Olskroken, *adjustment module*.

The final modules and interfaces will be further described and evaluated in 7.1 Detail Design. An illustration of the final concept can be found in Figure 50.

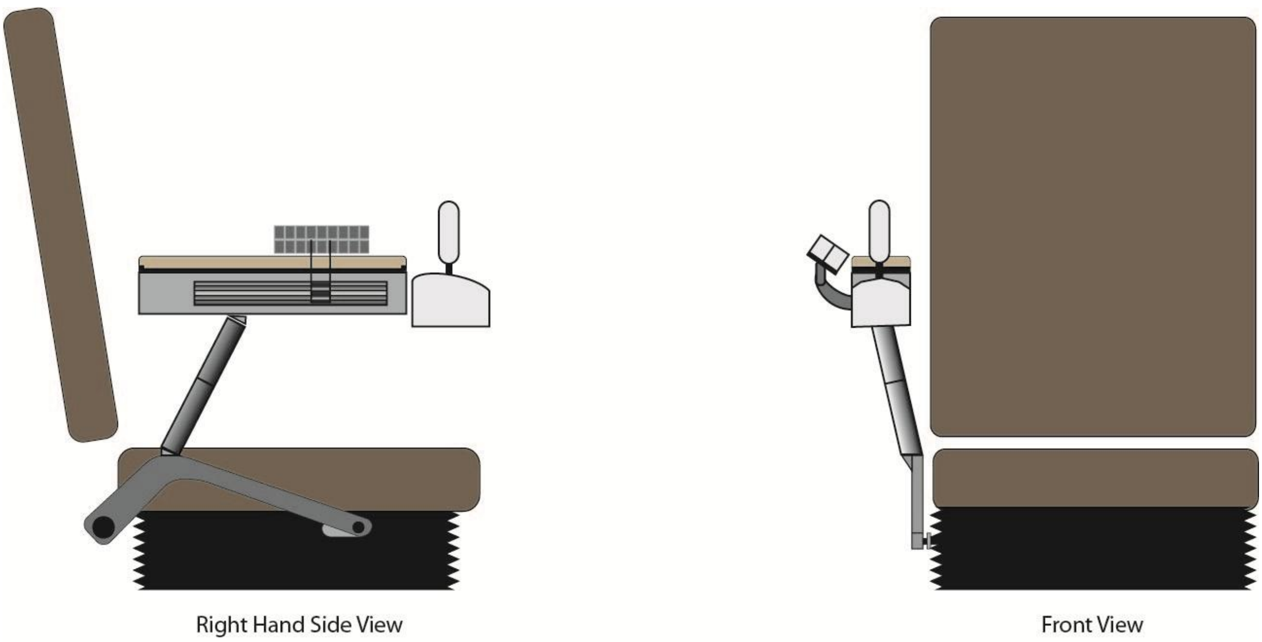


Figure 50. Final Concepts.

6.4 Touch Screen Module

A *Touch Screen Module* was generated as a compliment to the previously chosen modules. The touch screen will not be further developed; it will rather be kept as a concept for arguing its potential. The potential with a touch screen is that it would be possible to move functions from the side console into the touch screen and also add functionality that does not exist in the vehicles. The evaluation of the *Touch Screen Modules* can be found in Appendix G.

Concept Ebbot

This layout focusing on dividing the menu based upon functions, e.g. Operating, Engine, GPS etc., see Figure 51. This allows the operator to narrow the information to a certain area quickly.

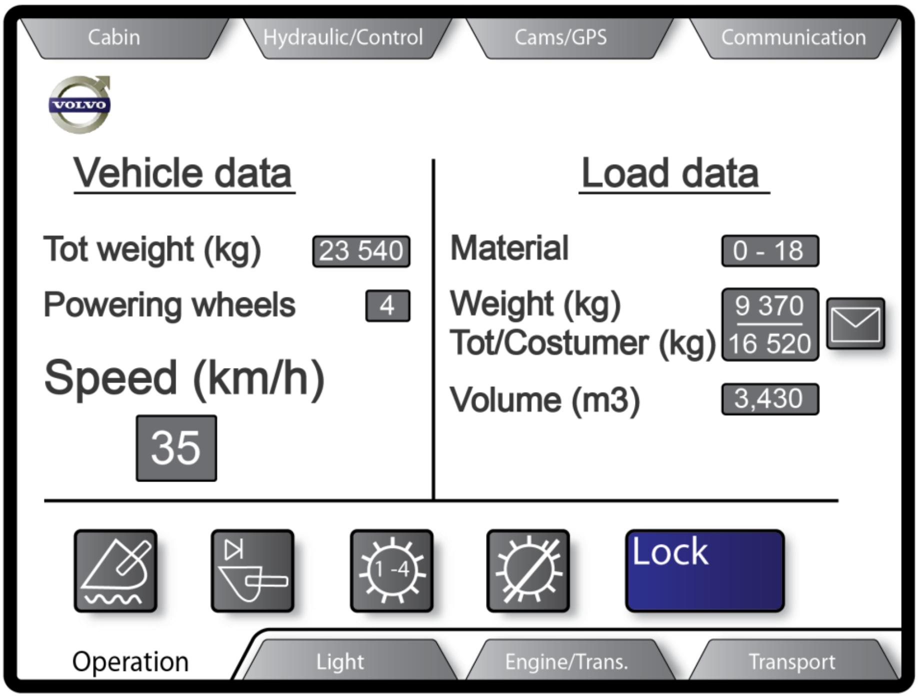


Figure 51. Concept Ebbot.

Pros:

- Easy to find a specific function.
- Possibility to arrange the most used functions in the same menu.
- Possibility to show linkage between different function within the same function group.

Cons:

- A lot of information presented at the same time.

Concept Nordstan

The layout has a more location orientated layout where the vehicle is divided into sections where each section controls the parts located in that area of the vehicle.

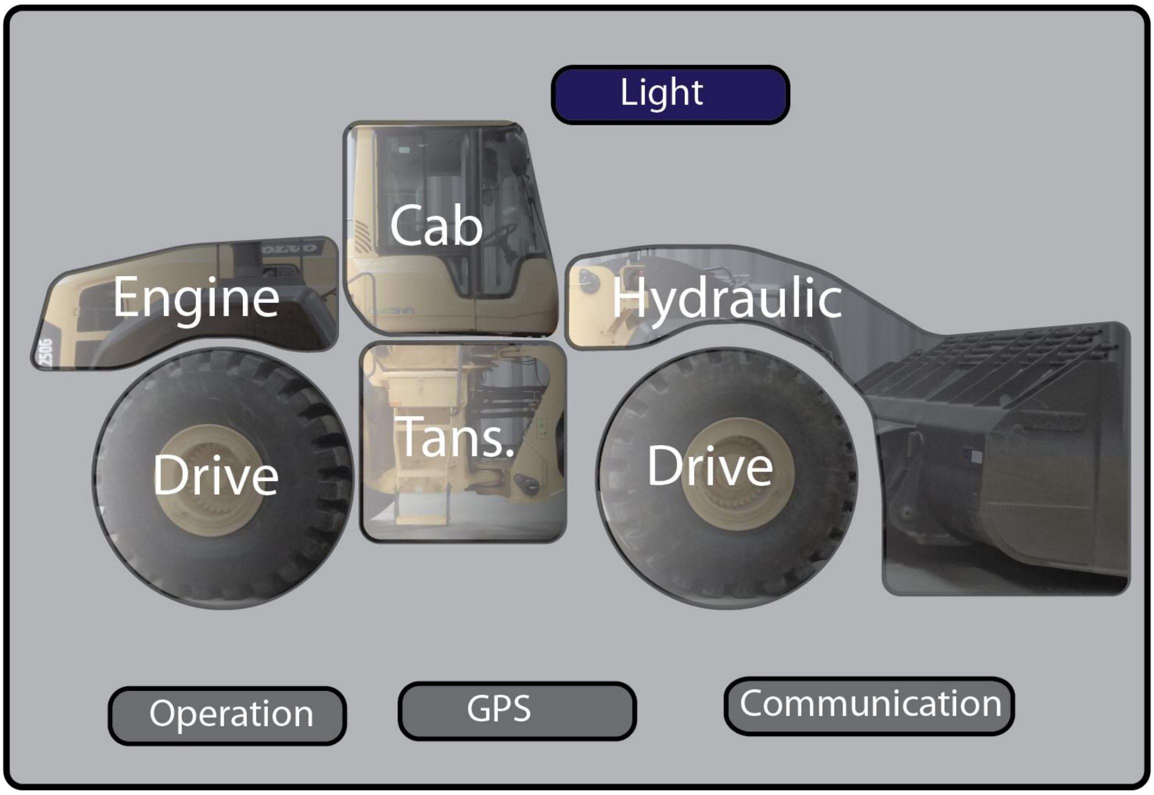


Figure 52. Concept Nordstan.

Pros:

- Visually easy to orientate in the layout.

Cons:

- Hard to define where the limit for each section should be drawn.
- Hard for the operator to know where the parts on the limits of a section is located.
- Demands the operator to have good mechanical knowledge of the specific vehicle.

6.4.1 Developed layout

Concept *Ebbot* were developed further from the illustration above to a functioning touch screen in order to simplify the presentation of the potential. Concept *Ebbot* was chosen since the potential was easier to illustrate from that layout. In Figure 53 it can be seen how one of these potential sub-menus could look.

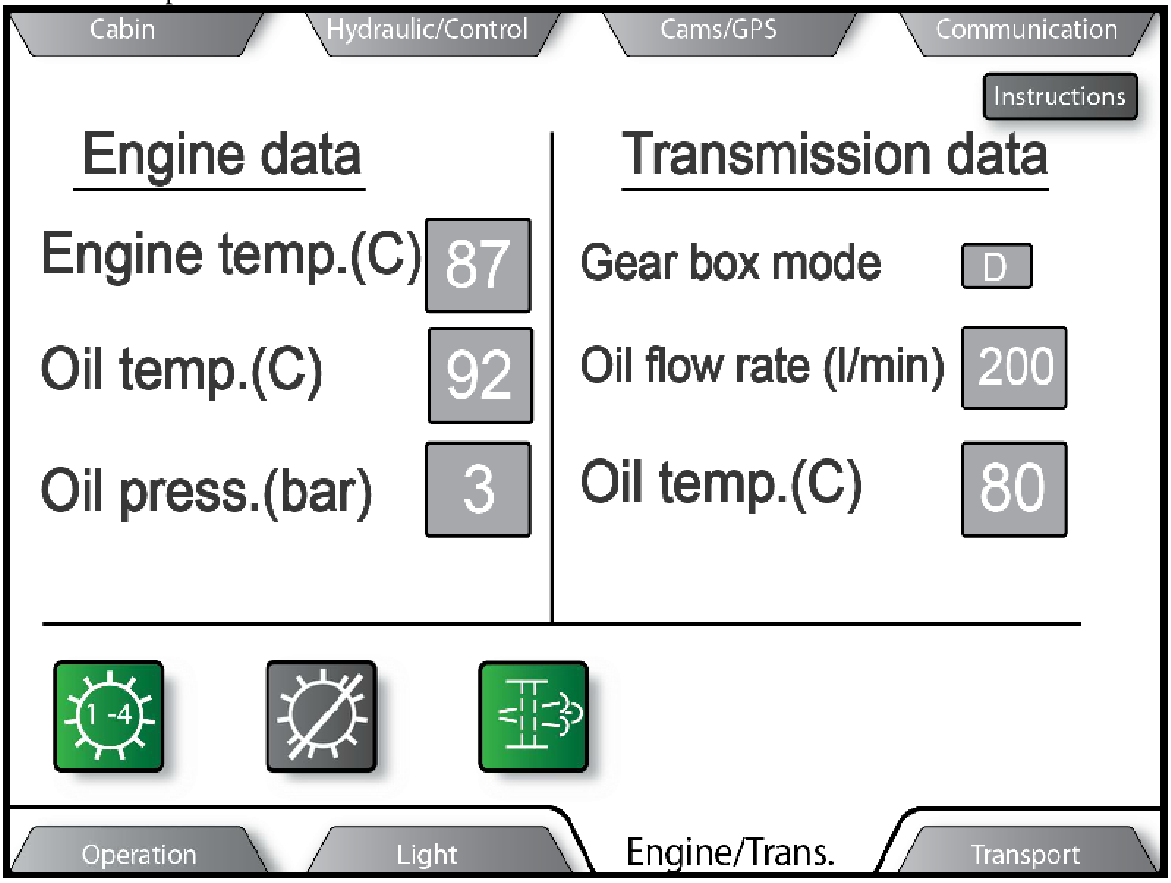


Figure 53. Engine/Transmission sub-menu in concept Ebbot.

6.4.2 Potential

By implementing a touch screen which handles most of the functions comes both pros and cons, it was included in the final design since it could bring a future potential to the product. The pros and cons are:

Pros:

- Possibility to make the user interface more ergonomic and increase the feedback from the system.
- A radical increase in modularity due to that the same unit can be used in different models with different software.
- Adapt the interfaces more specific to the needs of each model.
- Possibilities to link different functions to each other that today is operated separately.
- Can eliminate many space consuming features into one product, e.g. controls, manuals and other screens.

- Simplify installation of new attachments.
- Remind the operator and provide instructions for services.

Cons:

- Robustness could be an issue.
- Resistance to electronic products within construction equipment.
- Costly solution.

7 Final Design

This chapter will explain the final design of the side console. The final design is based upon the chosen concepts in the Concept Generation chapter; the further development was done by 3D modelling. A material selection was done for the final design as well.

7.1 Detailed Design

This section will describe the design work with the final concept and the underlying reasons for why the general layouts generated during the concept generation took the shape of the final design. First the design will be describes as an overview of the whole assembly and after that a detailed description of each module will follow. As mentioned before, the excavator has been the limiting factor for the design of the concept due to its limited space and great number of controls. It was for the same reason decided that the modelling will be of a side console in an excavator with the maximum number of controls. The modelling of the side console was performed on an excavator with 17 rocker switches, 4 knobs, 1 keypads and a 130 mm wide armrest (representing the most demanding aftermarket product). Apart from this the design had to be able to adapt to all combination between this case and a minimum alternative of 2 controls, 1 knob, 1 keypad and an armrest of 90mm wide (representing the factory mounted version).
During the final design phase it was kept in mind, even if it was decided to make another design for the compact vehicles due to cost, that as much as possible of the advanced solution should be applicable to the compact vehicles as well.

A total assembly can be seen in Figure 54. The view is taken from the front of the excavator. Included is the side console for both right- and left hand side. The reference surfaces provided from Volvo CE are showing the seat, seat suspension, left hand side window and casing and right hand side window and casing, including the door. This reference surfaces made it possible to implement the design in the current vehicle with one of the current seats. To walk through the design the first module described will be the one connecting to the seat and therefore the interface between the final concept and the current solutions.

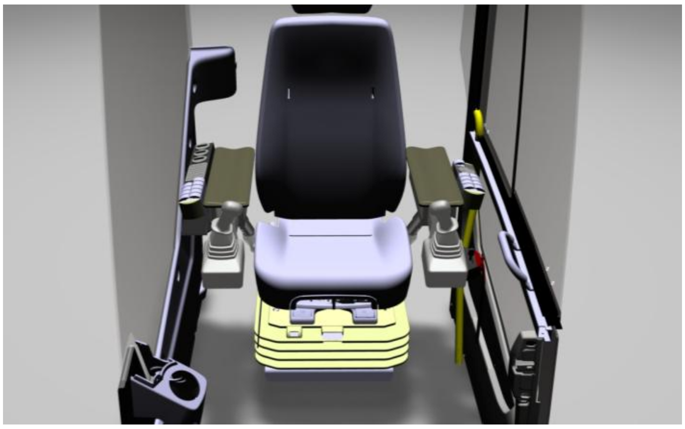


Figure 54. Rendering of the whole assembly in front view with reference surfaces.

The description will be made on the side console on the right hand side. This is possible due to that there are only a few differences between right- and left hand side; however these differences will be described later in 7.2.12 Symmetry. The modules presented in this chapter are slightly different from the ones presented in 6 Concept Generation due to that the detailed design required it. To clarify the location of the different modules Figure 55 shows an exploded view of the side console and following are the different modules:

1. Seat Module
2. Adjustment Module
3. Support Module
4. Base Module
5. Control Support Module
6. Control Module
7. Casing Module
8. Armrest Module
9. Manoeuvring Support Module
10. Manoeuvring Module
11. Extra modules
    a. Stability Lever Module
    b. Safety Module
    c. Storage Module
    d. Cup holder Module

Figure 55. Exploded view of the side console.

7.2 Detailed Module Description

Following is a detailed description of the design and interfaces of a specific part. The overall view will only be discussed in 7.1 Detailed Design.

7.2.1 Seat Module

As seen in Figure 56, the *Seat Module* is designed to fit the reference surface of the seat provided by Volvo CE. The *Seat Module* is designed so that it can be clamped to the seat by using the two existing bolts attached to the seat. By using this it is possible to test the prototype on an existing seat for further evaluation. Due to the great number of variation of seats among Volvo CE's product range it was not possible to find a common solution for all seats. It was therefore necessary to design a module with a specific interface towards the seat and a common one towards the *Adjustment Module*.
To be able to make the side console follow the motion of the seat the location of the attachment to the seat plays an important role. First of all it has to be attached above the suspension in order to follow the vertical motion but it has also to be attached above the sliding mechanism in the seat to follow the operator's horizontal adjustments of the seat. The horizontal adjustment could be solved by adjusting the side console separate.
In order to cope with the stress the *Seat Module* is made from 4 mm bent steel and with an extra reinforcing geometry, see Figure 56.
Interface towards the *Adjustment Module* is four bolts that hold the module and the side console in place see Figure 56.

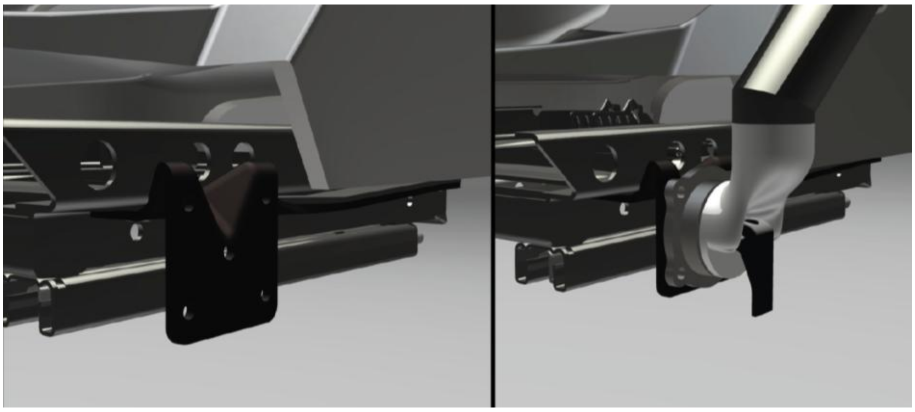


Figure 56. Rendering of the Seat Module.

7.2.2 Adjustment Module

The *Adjustment Module* is placed in between the *Seat Module* and the *Support Module* to allow the tilting motion of the side console. This is done by separating two pieces with an interacting patter against each other that when clamped together the surfaces hook on to each other and fix the side console in the specific position, see Figure 57 . With the shape of these surfaces the operator is allowed to adjust the side console in different steps, each with ~7degrees.
The *Adjustment Module* should be a homogenous part made from steel in order to cope with the stress and casting it is the only cost efficient way to produce the complex surfaces needed.

Clamping the two parts together could be done either by a bolt fitted with a knob or it can be done with an eccentric lock. As seen in Figure 57, the chosen solution was the eccentric lock and the reason for this is the placement of the locking mechanism. For an operator to enable the adjustability he/she has to reach quite far down the seat and also in a difficult angle; therefore, it was decided that the bolt and knob would be too hard to operate in that position and the eccentric lock would be a better alternative.

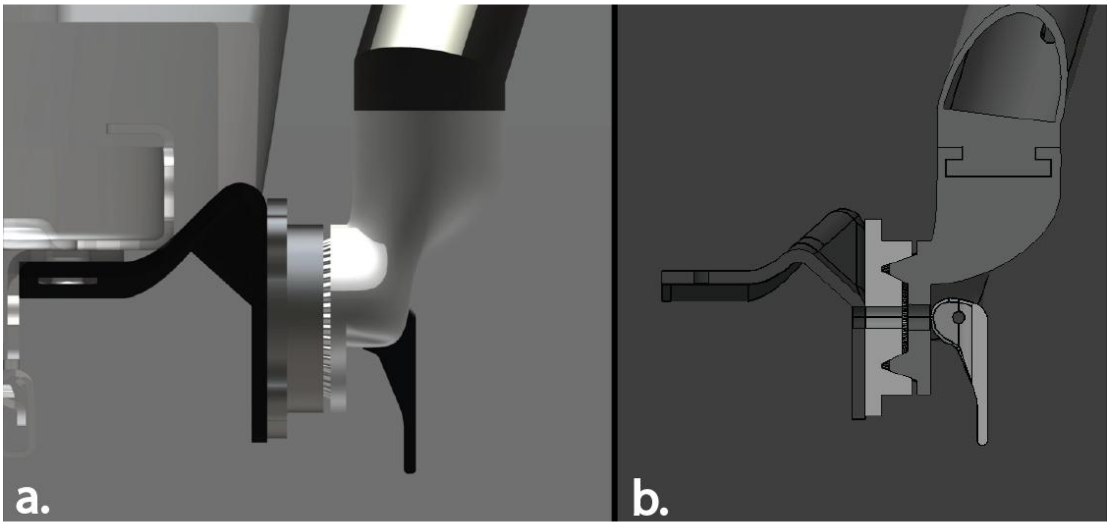


Figure 57. The Adjustment Module (a) and a cross section rendering (b).

7.2.3 Support Module

The *Support Module* could be part of the *Adjustment Module* but to allow for Volvo CE to sell vehicles with limited adjustment the modules were separated. The *Support Modul*e is used to support the side console but it also plays an important role for the adjustability of the side console. The design has to be strong enough to support the weight from the side console itself and the force applied to it from usage by the operator and at the same time be adjustable in x-, y-, z-direction and rotate around the pivot points, see Figure 58. To handle the stress the support has been designed from two steel tubes, 2mm thick, welded to two casted end pieces. The lower casted end piece is than mounted to the *Adjustment Module* while the upper one is mounted to the part of the *Support Module* that is connected to the *Base Module* called upper part of the *Support Module*, see Figure 58. The upper part of the *Support Module* is also casted in steel and it handles the interface with the *Base Module*. The upper and lower casted end pieces creates two rotation joints and there role in the adjustability is discuss later.

Figure 58. Support Module with the pivot points (x mark).

The adjustability in the vertical direction is made possible by sliding the two steel tubes relative to each other and thereby rises or lowers the armrest. The two tubes are going to be fixed in place by tightening a knob, which clamps the tubes together and locks them in place. The outwards adjustment is made possible from the two joints created by the casted end pieces since the rotation in these joints combined with the vertical motion from the two tubes makes it possible to move the side console in the horizontal plane, see Figure 59.

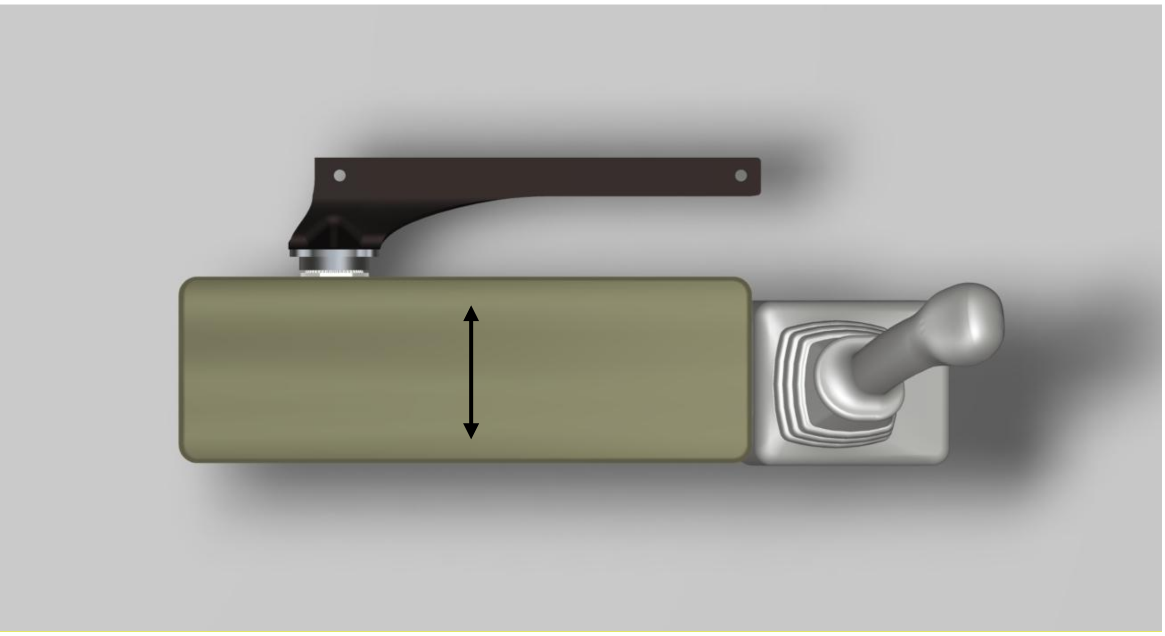


Figure 59. Rendering of adjustability in the horizontal plane.

Included in the *Support Module* is, as mentioned before, the upper part of the *Support Module* which handles the interface with the *Base Module*. How this interface is designed is controlled by the extrusion technique which is the planed manufacturing method for the

Base Module. As seen in Figure 60, the upper part of the *Support Module* will have two sliders that will join it with the *Base Module* by sliding inside the slots. Together with the upper part of the *Support Module* is also the sliding mechanism, see Figure 60.

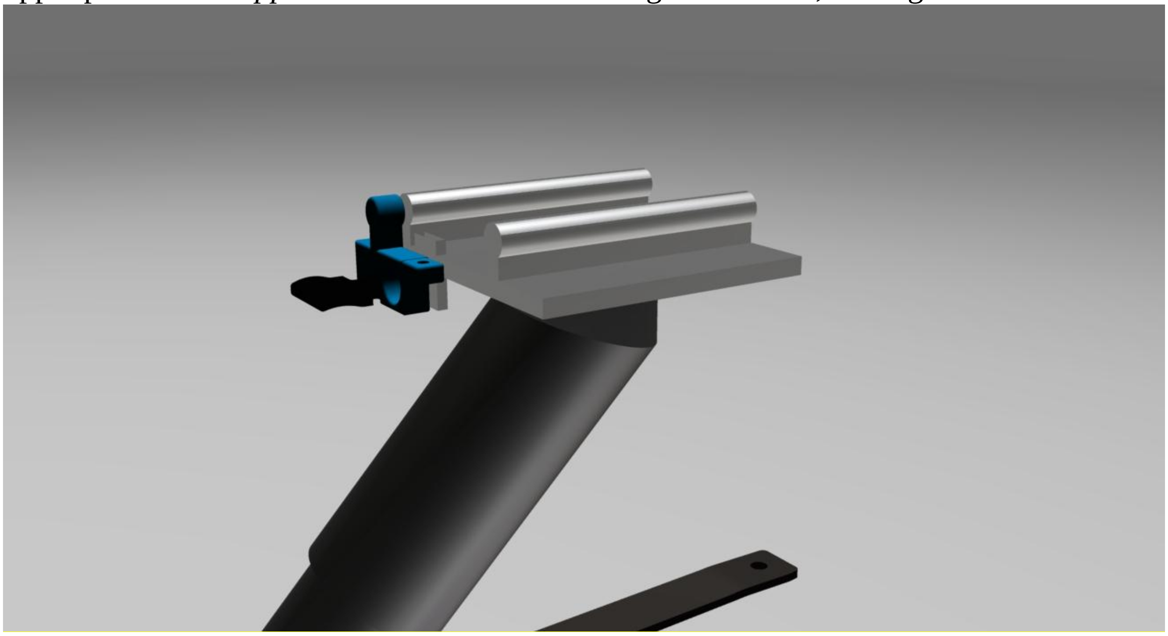


Figure 60. Sliders on upper part of the Support Module and sliding mechanism.

The sliding mechanism is only used for the left hand side and the purpose of it is to move the side console out of the way when the operator is getting in and out of the vehicle, a cross section of the sliding mechanism can be seen in Figure 61.

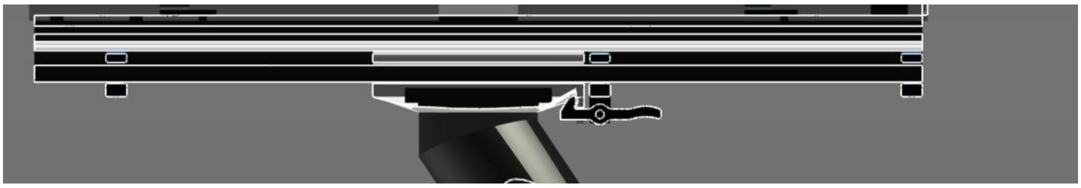


Figure 61. Cross section of the locking mechanism for the sliding mechanism.

Today this is solved by tilting the side console upwards and thereby gives space for entering and leaving the cab. However, this could be achieved with the new design as well by fitting a tilting mechanism to the *Adjustment Module* or using the *Adjustment Module* itself. Since this solution already exist and therefore has a very low innovative value it was decided to develop a new technique unique for the new design. Instead of tilting the side console the sliding mechanism allows the side console to slide backward when the upper part of the *Support Module* is released from the sliding mechanism through the spring inside the *Base Module*, see Figure 62.

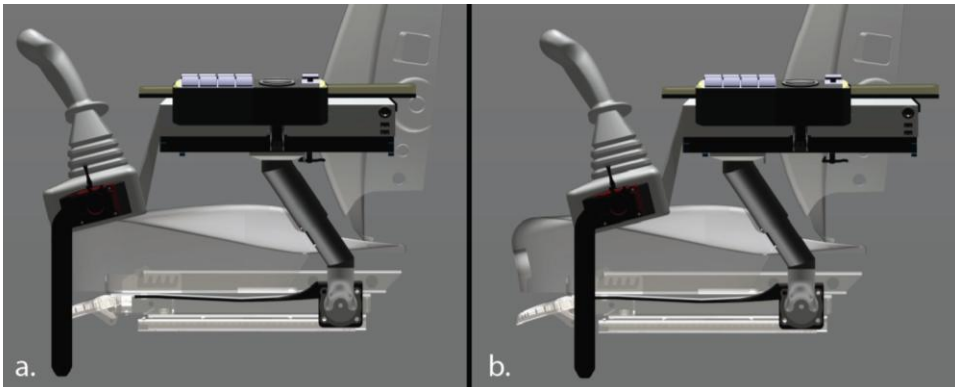


Figure 62. Side console in forward position (a) and rear position (b).

For the left hand side, it is the placement of the sliding mechanism that determines the position of the side console. While on the right hand side it is the upper part of the *Support Module* itself that is locked to the *Base Module* since the right hand side lack the need to be sliding backwards.
Due to these two rotating, marked in Figure 58, joints the design of the support can be used on both right- and left hand side just by rotating it to fit the configuration for the other side and by that reducing the number of parts.
For the models in a lower price range such as the compact excavator and compact wheel loader this support could be fitted with a fixed tube to restrict the degrees of freedom and reduce the cost. The same option could be offered as a cheaper alternative to the vehicles that could be fitted with the adjustable support.

7.2.4 Base Module

The *Base Module* makes the foundation for the side console and it is to the *Base Module* that almost all modules are attached. In order to create an as adaptive interface as possible it was decided to manufacture the *Base Module* from aluminium extrusion with a few additional operations to drill the holes for assembling the casing support and the manoeuvring support, see Figure 63.

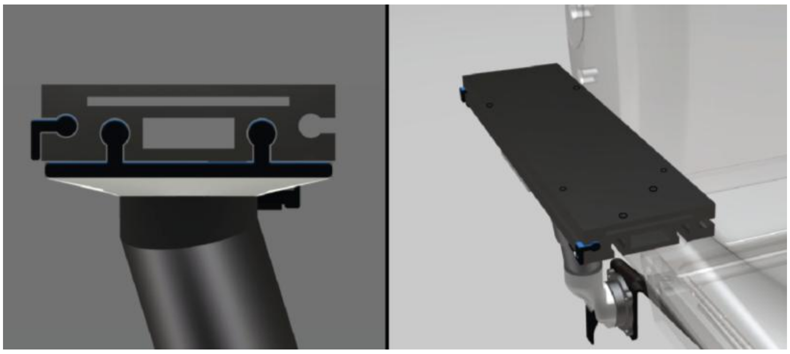


Figure 63. The Base Module from a front view and a top view with the holes highlighted.

These sliding paths allow the attached modules to slide back and forward and are the basis for the high level of adjustability of the design. This specific design also allows the *Base Module* to be used at both right- and left hand side without any further adoption.

Included in the *Base Module* are a number of stops in the sliding paths in order to stop parts falling out of the slides while adjusted by the operator. On the left hand side one of these stops also provides the end position when the side console is slide backwards when leaving or entering the cab.

7.2.5 Control Support Module

The *Control Support Module* should be integrated with the *Control Module* but to gain sufficient support in the prototype they were separated. *The Control Support Module* is the linkage between the *Base*- and the *Control Module*, see Figure 64. Its main purpose is to allow the adjustability while being robust enough for the controls.

Figure 64. Control support module.

To lock it in place it is designed to clamp the *Control Support Module* to the *Base Module* wall by tightening a bolt connecting it with a locking mechanism inside the slides of the *Base Module*.
The *Control Support*- and *Control Module* are designed in such a way that if needed on the well-equipped models an extra *Control Support Module* could be added to increase the robustness. However, this requires further physical testing which is not included in this thesis.

7.2.6 Control Module

The design is then divided into one centrepiece which is the foundation of the *Control Module* where the *Control Support Module* is connected. This part of the module is where the other functions are added and the wiring is gathered before it enters the *Base Module*. The part consists of the more robust steel layer at the bottom and onto that the functional casing is added, see Figure 65. There are two different kinds of centrepieces, one for keypads and one for knobs which means that the module can be built with the controls needed for the specific vehicle.

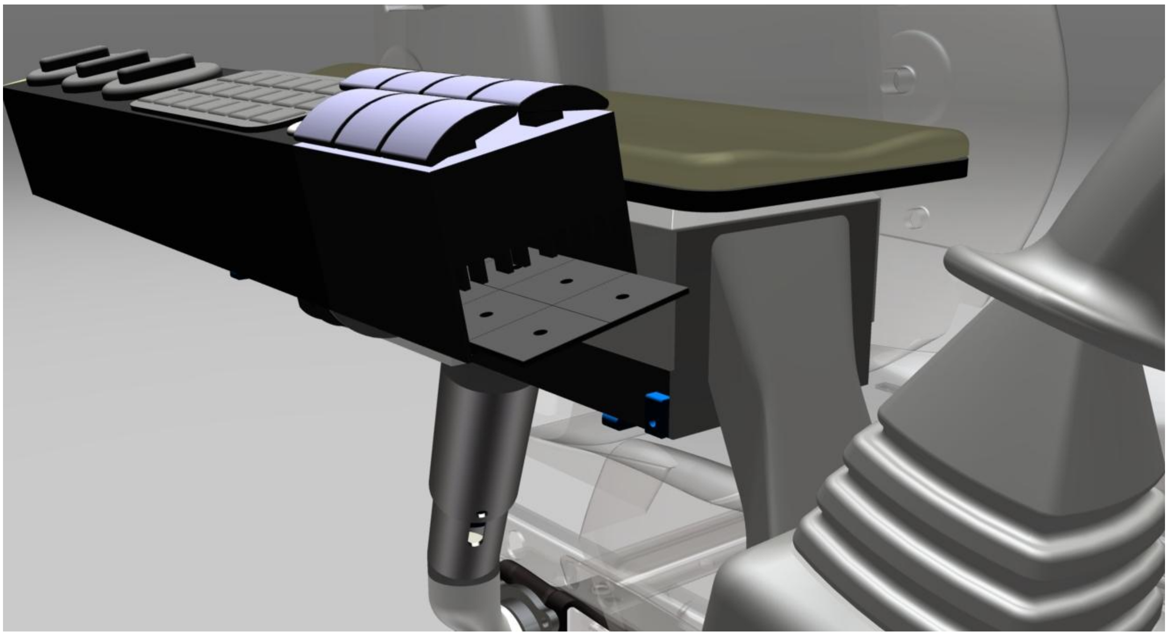


Figure 65. Rendering of the control module, both the steel and plastic layers can be seen.

The controls are added with the same structure as the centrepiece itself. First one of the robust steel pieces is added and onto this the functional control with its plastic casing is mounted, see Figure 66. Since the steel piece is the size of two controls in the x-direction, it either has to be added two rocker switches or one “empty module” to fill up the gap. The procedure is the same when a knob is added apart from that the knob is twice the size, lengthwise, compared with a rocker switch so it uses two of the steel pieces. By standardise the size of the controls and knobs it is possible to add them to the same design with some common parts.
As an aesthetic ending on the design a special end piece is added; this also seals the electronics from the operator.

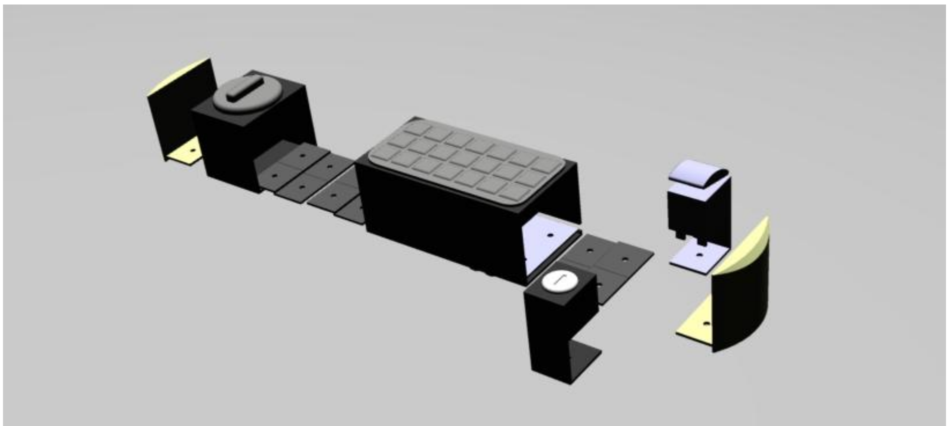


Figure 66. Exploded view of the Control Module.

This design makes it possible for the operator to add functions as more attachments are fitted to the vehicle. It also allows him/her to arrange the controls in what way he/she wants and enables the possibility to bring forward the controls that are used often and hide the others. It also allows for aftermarket companies to add new functions to the side console without having to make big changes to the console.

7.2.7 Casing Module

The *Casing Module* consist of two major parts, the casing itself and the support for the casing and the armrest. The casing support is mounted on to the top of the base by four bolts, see Figure 67. This interface has been kept as simple as possible due to the lack of adjustability.

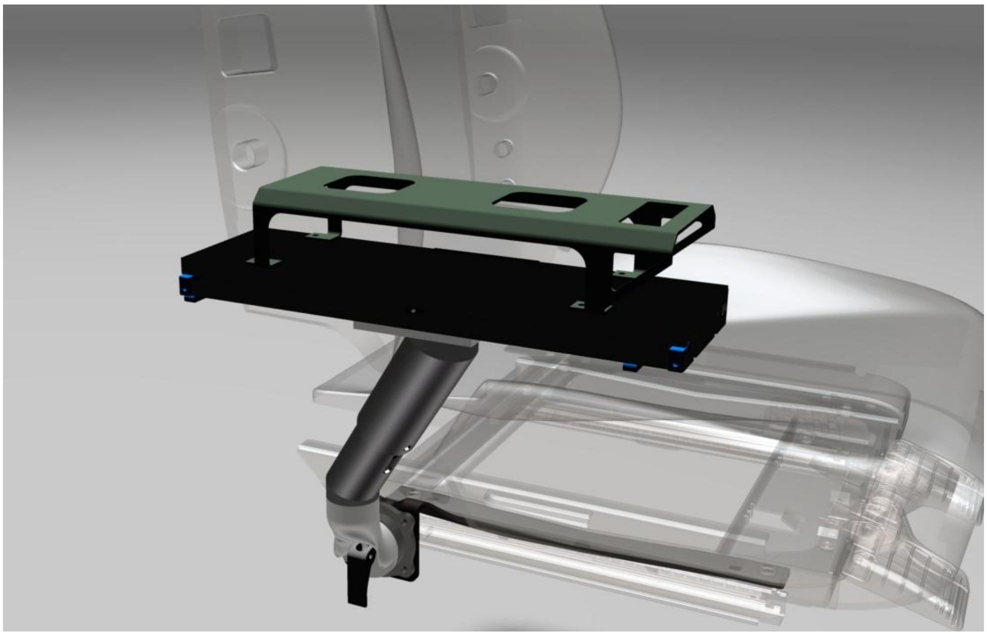


Figure 67. Casting support module in green.

The *Casing Support Module* will be made from 2 mm bent steel and will not only be the support for the casing- and *Armrest Module* it will also provide the fastening for both of them. The casing will hook on to the casing support in the rear end, see Figure 69.

The casing itself will be the aesthetic part that covers the mechanical and electrical parts, see Figure 68. The casing will allow the wiring from both the control- and the *Manoeuvring Module* to enter the casing on the side respectively in the front and later be gathered and leave in the back of the side console.
Included in the casing there will be one 12V power- and two USB-sockets to supply the operator with charging possibilities and a service socket for maintenance. Also included is a separate casing to cover the path in the *Base Module* from the *Control Support Module*. It could have been designed one for each side due to that the cables to the *Control Module* has to pass through the right respectively left side; however, it was decided that a casing prepared for two sides with one extra casing to cover the holes on each side would bring a lower cost. This reasoning is based upon that there is a lower cost to have one large part together with a small in production compared with two large parts.

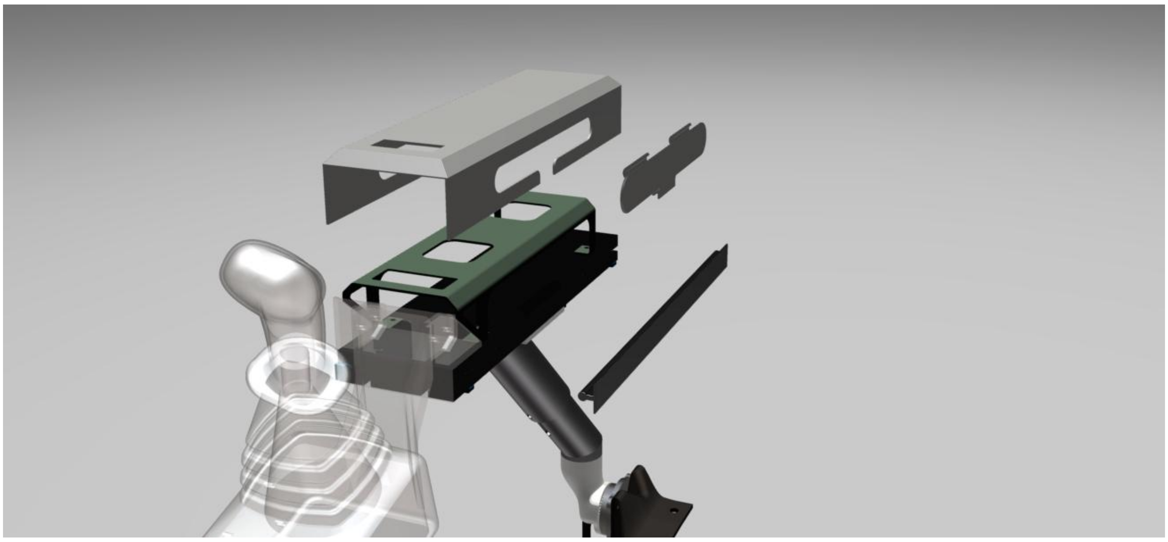


Figure 68. Exploded view of the casing.

7.2.8 Armrest Module

The *Armrest Module* is designed to handle the variety of different armrest mounted to the side console by the aftermarket modifications. Since the armrest is one of the things changed in the cab it was kept in mind that this assembly should be simplified compared with the current solution.
The armrest will be mounted by hooking on to the casing support in the front and at the same time clamp the casing in place. The armrest is than fasten with two screws in the rear of the casing, see Figure 69. When the armrest is fasten to the casing both of them are locked in place by their combined attachments. The casing stops it from sliding backwards and sideways while the armrest stops it from sliding forward.

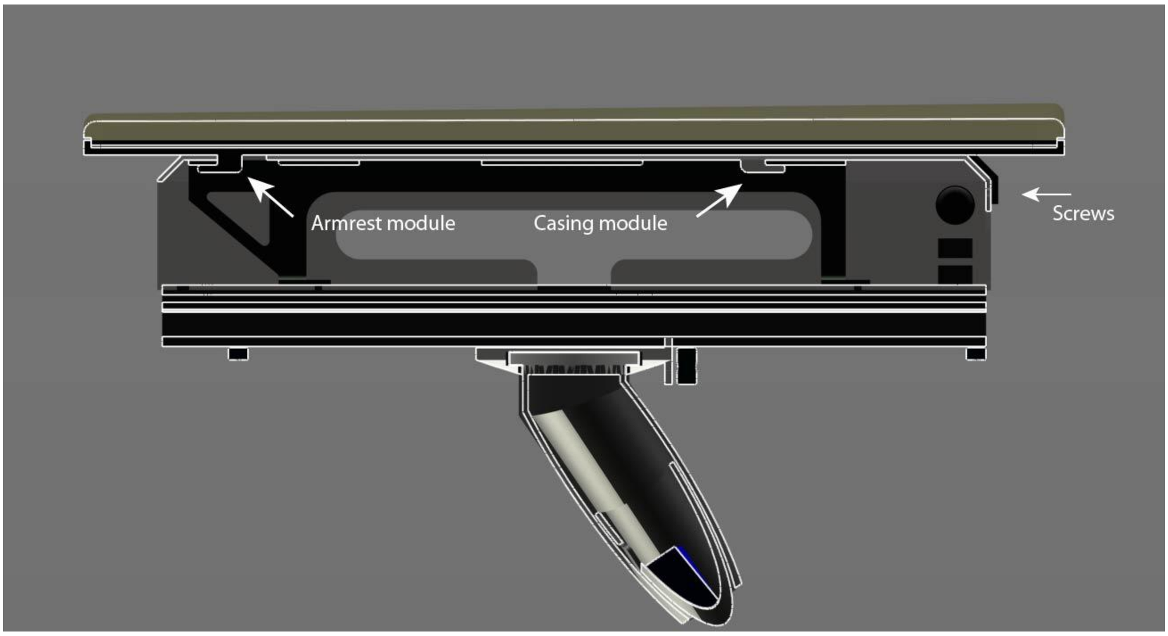


Figure 69. Cross-section of casing, casing support and armrest.

The armrest will cope with the variation in size from a width of 90mm to 130mm. It will also consist of one plastic part handling the interface with the *Casing Module* and one softer and more ergonomic part on top in contact with the operator.

7.2.9 Manoeuvring Support Module

In the same way as the armrest is changed during the aftermarket modifications the focus on the manoeuvring support has been to simplify the assembly of it while providing a robust solution. The design allows the *Manoeuvring Module* to be changed with four bolts easily reachable when the casing is removed. This could be further simplified with two bolts but that requires physical testing.
The manoeuvring support also allows for wiring from the *Manoeuvring Module* to pass through it into the casing, see Figure 70. To allow it through the manoeuvring support it is possible to hide the cables inside the *Manoeuvring Module*. The *Manoeuvring Module* will be manufactured from casted steel.

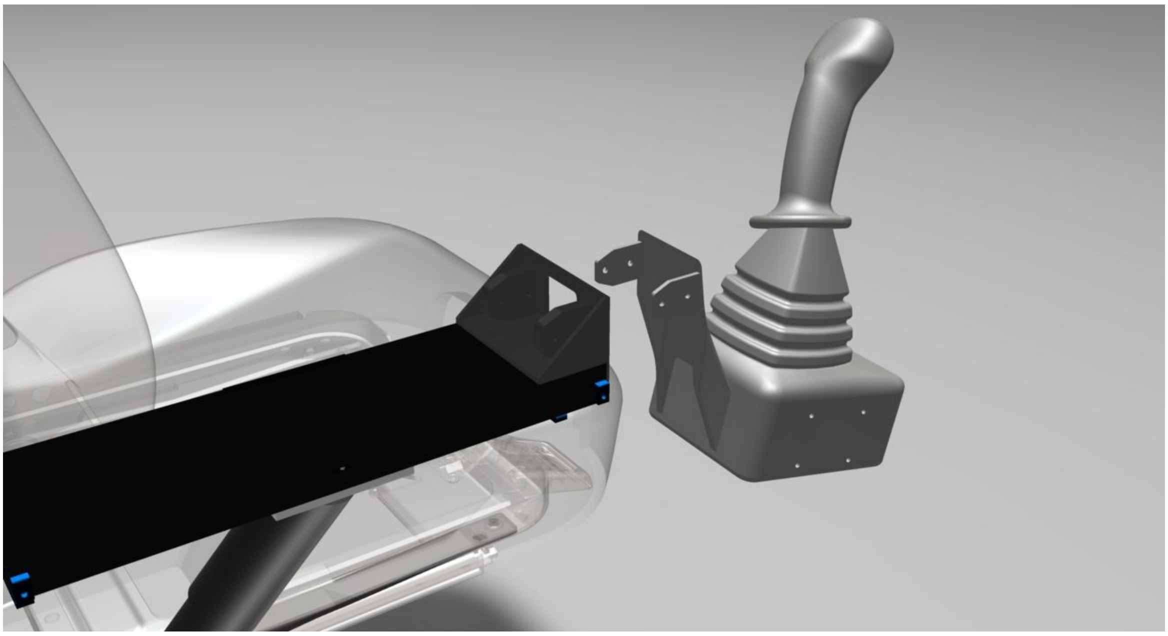


Figure 70. Rendering of the manoeuvring support module.

7.2.10 Manoeuvring Module

The designed *Manoeuvring Module* is a combination of the structure and the casing of it, see Figure 70. The reason for this is that there would be no added value for this thesis to design the internal structure of the module.

The *Manoeuvring Module* handles the variety of the manoeuvring units among the different models. From this variation it fulfils two purposes; first, a support for the different controls itself and secondly the location of the unit. The different manoeuvring units can vary from a single joystick to four levers in a row; therefore, the *Manoeuvring Module* has to have a unique interface to the specific manoeuvring unit and at the same time have a common interface towards the *Manoeuvring Support Module*. The current solutions can vary a lot in position. The position of the hand is more or less the same in all the cases but the base of the unit can vary from; in level with the armrest to 110 mm below it. In order to get the grip surface at the correct position the *Manoeuvring Module* has to cope with these differences.

The *Manoeuvring Module* is also the base for the *Stability Lever Module* and the *Safety Module* used in the excavator, see Figure 71.

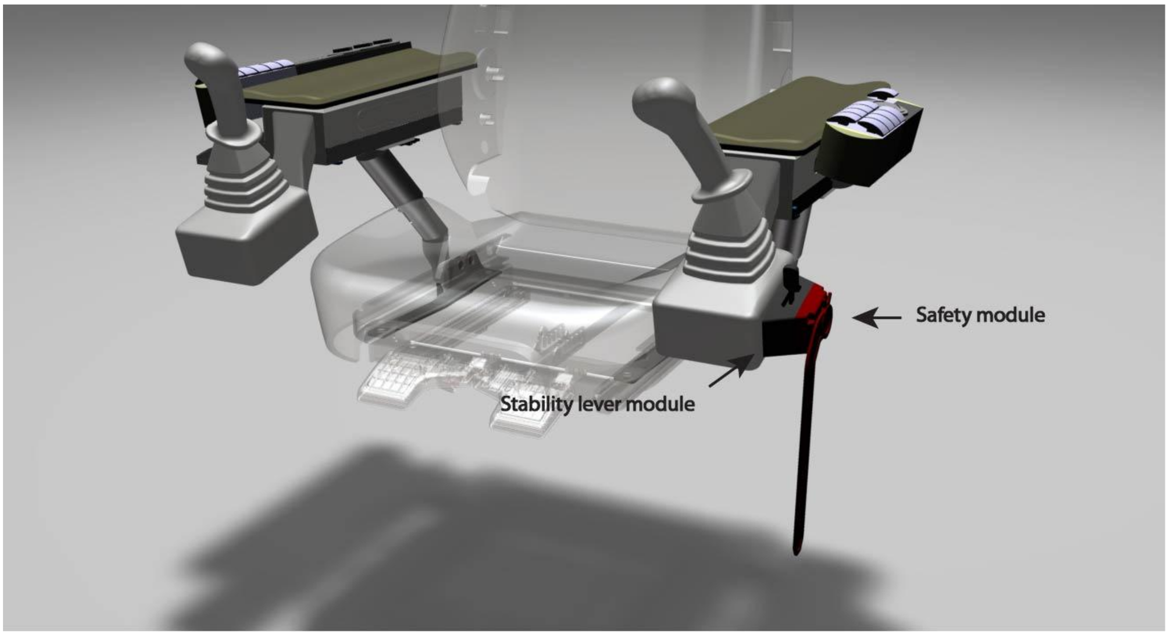


Figure 71. Rendering of manoeuvring-, stability lever- and safety module.

7.2.11 Extra Modules

There are a number of modules that are specific for some models or they can vary due to the costumer's specifications when ordering the vehicle. These extra modules are the following

Stability Lever Module

Most of the excavators are fitted with a blade or support legs and these functions require a separate lever to be controlled. However, the largest excavator does not have this function and it therefore had to be considered as a separate module instead of being included in the *Manoeuvring Module*.
This module will be mounted on the outer side of the *Manoeuvring Module* on the left hand side, see Figure 71.

Safety Module

The *Safety Module* is the lever that prevents the operator to operate the vehicle while not seated in the correct position, see Figure 71. This module has to be placed with no other modules outside it due to that the lever has to be able to rotate freely. It is therefore placed on top of the *Stability Module*.
For those vehicles that are not equipped with a *Stability Module* the *Safety Module* can be mounted using the same holes as the *Stability Module*.

Storage Module

Some of the costumer required extra space to place phones and pads and therefore it was decided that there had to be a *Storage Module*. The *Storage Module* will be mounted on the side of the side console and under the *Control Module*. However, due to the modular interface of the *Base Module* the operator can choose whether he/she wants to have it in the front or the back of it, see Figure 72.

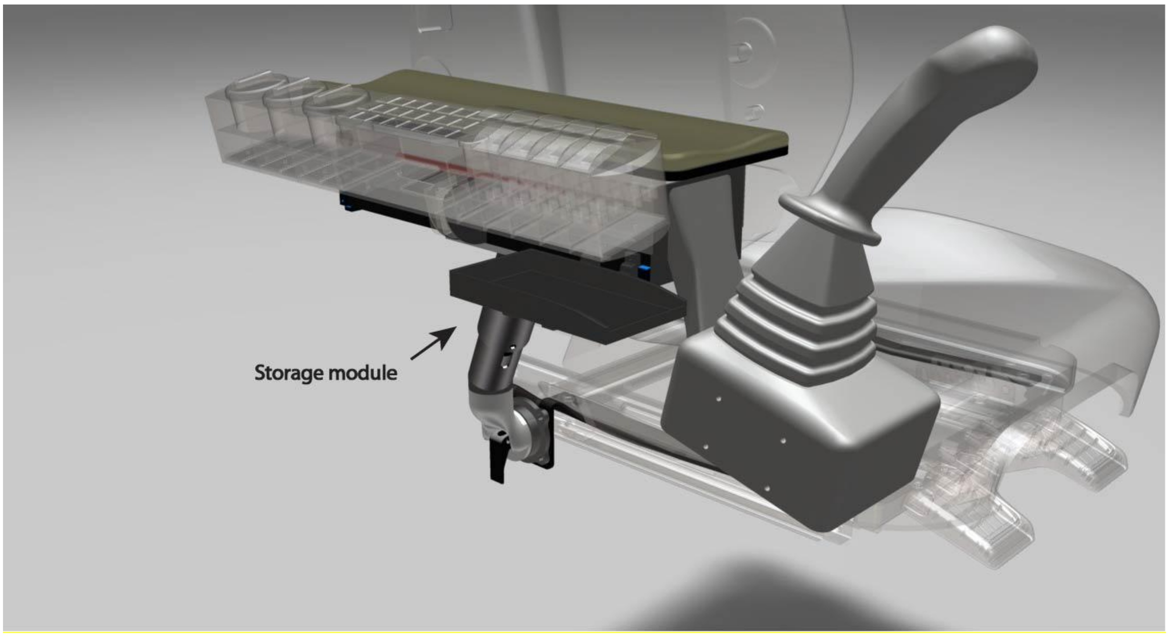


Figure 72. Rendering of the storage module.

Cup Holder Module

The *Cup Holder Module* could be mounted in the same way as the *Storage Module*. However, that would cause some issues with the models with a large number of controls. It is therefore recommended to replace the *Cup Holder Module* to a casing inside the cab or with a suction cup on a windscreen.

7.2.12 Symmetry

The design presented above has one major advantage with the symmetry of right- and left hand side since all parts can be used for both sides apart from:

- **Seat Module** due to the asymmetric shape of the seat attachment surface.
- **Manoeuvring Unit** comes quite obvious that it cannot be symmetric since the human body is not. However, the *Manoeuvring Module* is symmetric if the manoeuvring unit is not considered.

This will lead to a great reduction of article numbers which has a direct connection with cost reduction.

7.3 Touch Screen Module

As an optional module to the *Control Module* a *Touch Screen Module* was developed parallel with the more traditional *Control Module*. The reason why not one of the solutions where chosen as the final design is due to that both Volvo CE and market demanded a solution with ordinary controls. The market demanded it is because if a touch screen option is going to be introduced to the market; during the phase of transition from ordinary physical controls to a touch screen there has to be two options for the costumer to choose between. Therefore was the touch screen considered as an option and developed parallel to the other modules.

It is important to point out that no deeper cognitive ergonomic evaluation of the design has been done and the work has focused upon the modular potential of a touch screen implementation. The only ergonomic point of view that has been considered is the request of simplicity for a product such as this which was discovered during the interviews with operators and aftermarket. Furthermore, it was ascertained during the forest machines benchmarking that touch screens function well in rough environments.
It could be argued if a touch screen is best option. Some argue for touch screens and some for knobs that operate a menu, common in the car industry. However, it was decided that for construction equipment, a highly sensitive knob together with that the vehicles operating at low speeds it would be most suitable with a touch screen. Another factor was the only chance to test it was with a touch screen and if a touch screen turned out not to be suitable it could easily be transferred to another solution.

7.4 Material Selection

The material selection was made by selecting essential criteria that the material would be subdued to instead of selecting a specific metal alloy or polymer structure. This means that the material selection is specified in more general terms which ensure that a wider choice of materials is available. The material selection is divided into three different selections:

- **High Load Bearing Structure:** This is the part of the side console that will take up most of the forces applied to the console.
- **Low Load Bearing:** The main purpose of these parts is to support other parts in the structure of the side console. These parts are not supposed to be subject to the forces of the load bearing structure.
- **Polymer components:** Some parts will be made out of plastic.

7.4.1 High Load Bearing Structure

The modules that are included in this structure are:

- *Seat Module*
- *Adjustment Module*
- *Casing Support Module*
- *Manoeuvring Module*
- *Control Support Module*
- *Control Connection Module*
- *Centre Control Module*

Even though the high load bearing structure should be as robust as possible it should also have as low weight as possible which will make it easier to assemble. Cost is as always of great importance. These criteria lead to the following material parameters (MP) which were used in the selection. Both material parameters should be as low as possible.

$$MP_1 = \frac{\rho \times P}{E}$$

$$MP_2 = \frac{\rho \times P}{\sigma_y}$$

Where: P = Price
ρ = Density
E = Young's Modulus
σ_y = Yield strength

By using these factors in CES a wide selection of materials was presented. Table 4 and Table 5 shows the materials that were seen as suitable for this structure.

	Density (kg/m^3)	**Price (SEK/kg)**	**Young's Modulus (GPa)**	**Yield Strength (MPa)**
Low carbon steel	7,8-7,9 x 10^3	4,27-4,7	200-215	250-395
Low alloy steel	7,8-7,9 x 10^3	5,51-6,06	205-217	400-1500
Stainless steel	7,6-8,1 x 10^3	49,3-54,2	189-210	170-1000

Table 4. Material properties.

	MP_1	MP_2	$MP_1 \times \mathrm{MP}_2$
Low carbon steel	172,7	94	16233,8
Low alloy steel	220,6	31,9	7037,1
Stainless steel	2090,6	439	917773,4

Table 5. CES generated material parameters

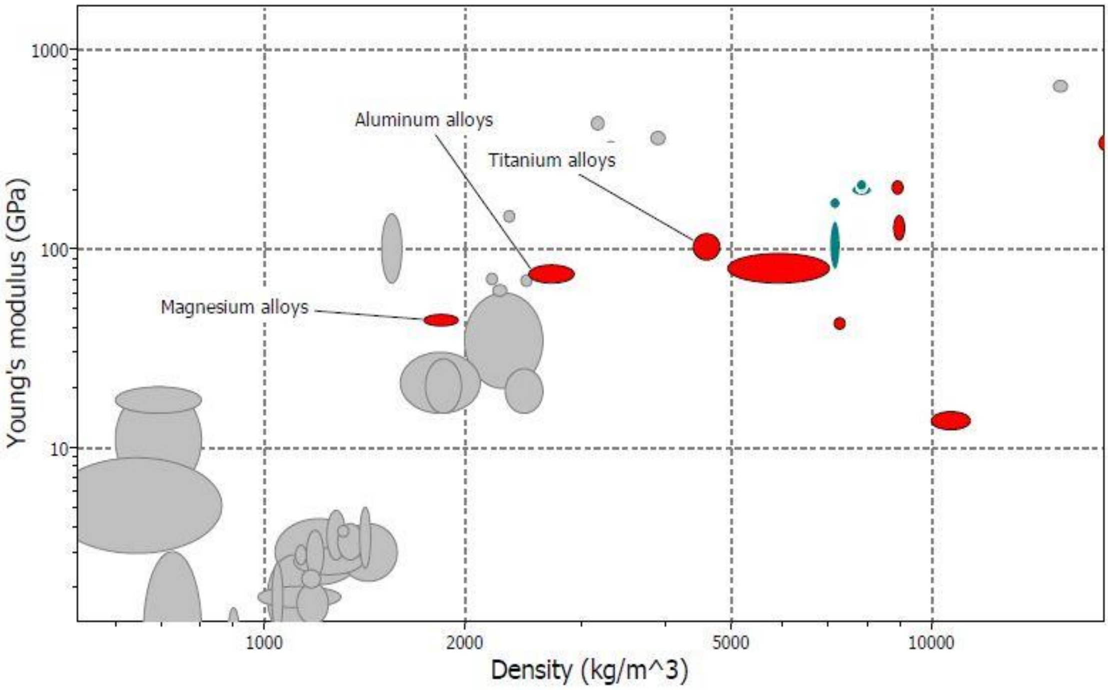
Stainless steel is expensive to use and has the highest material parameters. Low alloy steel received the lowest total score in the material parameters. Therefore it is seen as the most suitable material for this structure.

7.4.2 Low Load Bearing Structure

The modules included in this structure are:

- *Base Module*
- *Manoeuvring Support Module*

This structure is called low load bearing structure since it is mainly used in modules that will not be subject to high forces. The main property for this material is low density; the material should however also have good tensile strength. By plotting density against tensile strength Graph 1was given in CES. The three materials that were seen as most suitable are presented in Table 6.



Graph 1. Plot of density against Young's modulus.

	Density (kg/m^3)	Young's modulus (GPa)	Price (SEK/kg)
Aluminium Alloys	2.53 - 2.9 x 10^3	68 - 82	16.2 - 17.8
Magnesium Alloys	1.74 - 1.95 x 10^3	42 - 47	32.3 - 35.6
Titanium Alloys	4.4 - 4.8 x 10^3	90 - 120	394 - 433

Table 6. Suitable materials for the support structure.

The support structure will be made out of aluminium since it is considerably less expensive than the other materials and has sufficient Young's modulus and density.

7.4.3 Polymer Components

The components included in this material selection are:

- *Base Module casings and stops*
- *Rocker switches*
- *Knobs*
- *Keypad holders*

The plastic components will have to handle different types of environments. The vehicles are used in environments that can include both alkalis and acids which will affect the components. The components will be manufactured by injection moulding which means that the polymers will have to be a thermoplastic or thermosetting material. Price will always be an important factor when producing products. The vehicles will be manufactured in large quantities which mean that a small difference in SEK/kg can make a big difference in the long run. The polymers selected in CES are presented in Table 7.

Material	Water	UV Radiation	Weak alkalis	Weak acids	Tensile Strength (MPa)	Price (SEK/kg)
PVC	Excellent	Acceptable	Excellent	Acceptable	44,1-60	18,2-20,1
PE	Excellent	Acceptable	Acceptable	Excellent	13,3-26,4	19,3-24,1
PP	Excellent	Acceptable	Excellent	Excellent	23,4-24,6	11,3-12,4

Table 7. Selection of polymer materials.

The components will be manufactured in polypropylene (PP) since it is the polymer that is most suitable. It functions well in different environments, has a sufficient tensile strength and has a lower price than the other polymers.

8 Evaluation

The final design of the side console was evaluated in order motivate further development It was evaluating regarding robustness, ergonomic issues as well as environmental impact, these evaluations were performed on the 3D model described in the final design chapter. An evaluation of the produced prototype was also carried out.

8.1 Finite Element Analysis

The FEA simulation was carried out in order to see if there were any issues with to great displacement causing a weak felling when used by the operator. The simulation was carried out on the side console of the right hand side with the design presented in DETAILED DESIGN and with the settings presented in METHODODOLOGY, FINITE ELEMENT ANALYSIS. The global size of the mesh elements where determined by decreasing the size until the displacement value converge, see Figure 73. The chosen value was a global size of 9 mm and this value was taken when the simulation had converged and just before the displacement result started to fluctuate again and the model is no longer valid. This was also noticed for the computation time. When the computational time starts to increase drastic the global size are getting close to where the model was no longer valid; this could be seen right after 9 mm, see Figure 73. The result from the simulation was:
Maximal displacement: 5 mm, seen as red in Figure 73

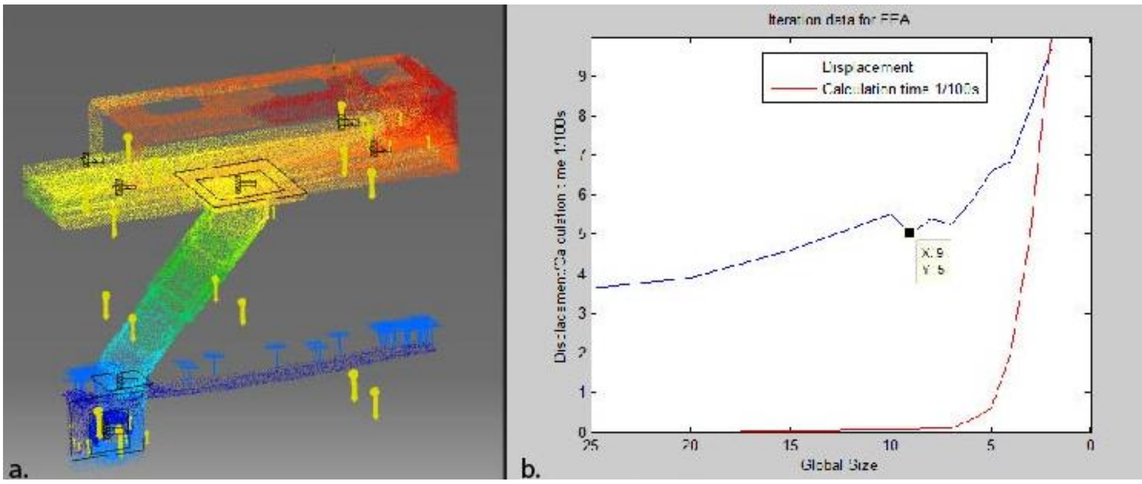


Figure 73. FEA result for Displacement (A) and iteration data (b)

This value was considered to be within the tolerances and therefore was no further reinforcements implemented.

8.2 Ergonomic Simulations

As mentioned in 5.5 Physical Ergonomics, the placement of the current arm position was not considered in this thesis. However, the new design eliminated the option for excavators to adjust the armrest in relation to the *Manoeuvring Module* which is possible on the current solution. During the design this feature was considered as a consequence of the chosen solution and not a value adding function. To validate this reasoning the final design was tested with a human mannequin. This was done to see if there was any issues regarding the hand positioning around the grip surface of the manoeuvring unit for a 5th percentile female and a 95th percentile male. If such an issue had occurred the feature with adjustable armrest compared with the *Manoeuvring Module* would have had been needed. The result from the simulation can be seen in Figure 74

When the result was analysed no such problem could be found and the adjustability of the armrest and the *Manoeuvring Module* was considered as redundant.

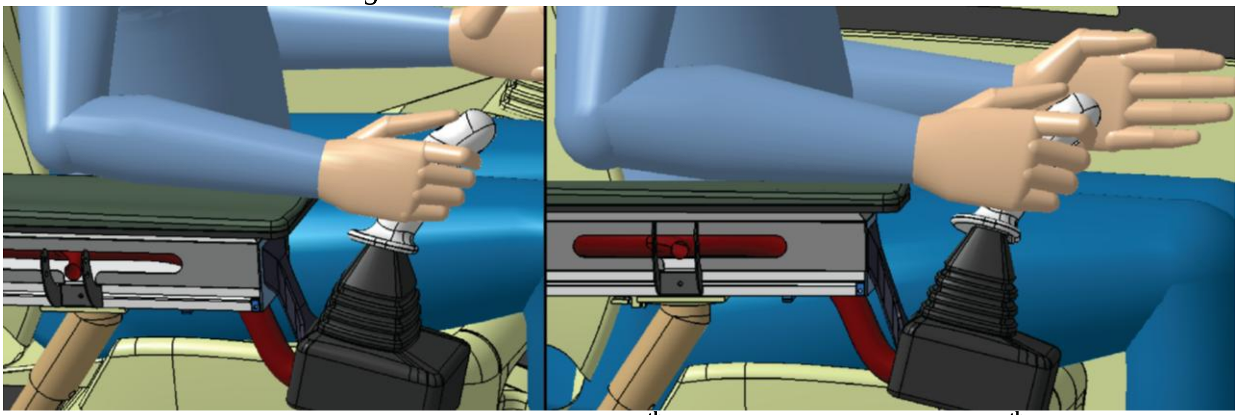
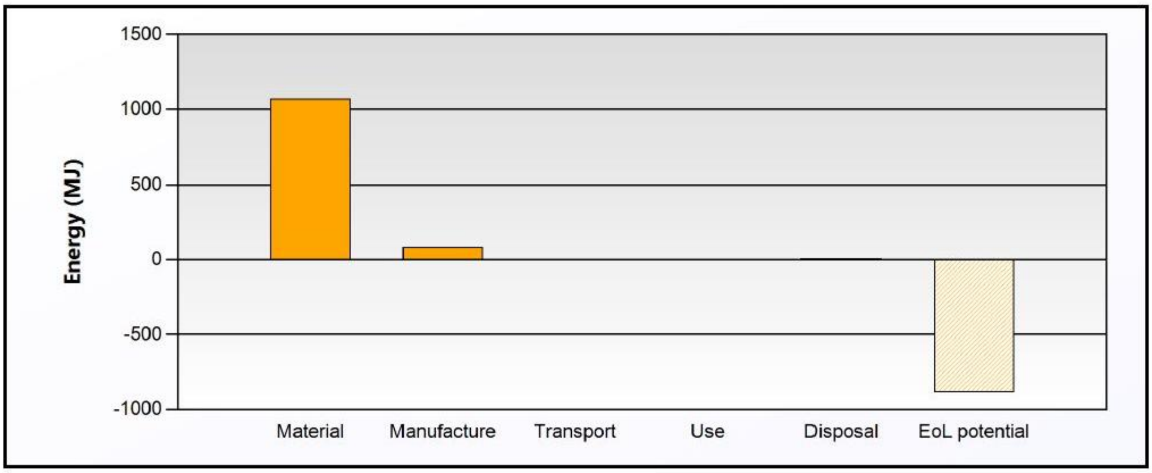


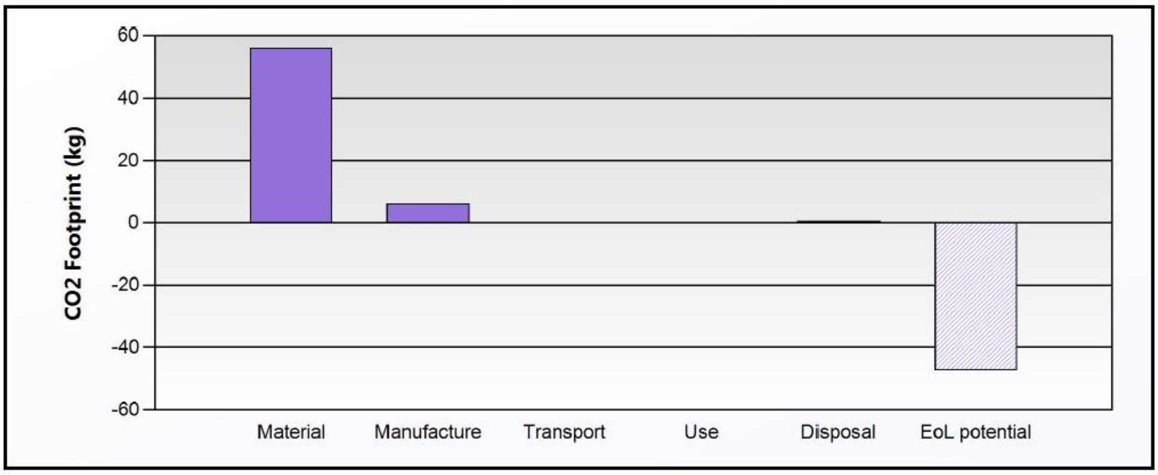
Figure 74. The results from the ergonomic simulations, 5th percentile female (left) and 95th percentile male (right).

8.3 Environmental Impact

It is important that all of modules included the side console are designed with environmental impact in mind. A life cycle analysis of the environmental impact of the side console was performed in order to analyse the side console’s impact. For this, the mass of each material and the manufacturing method of the different modules were implemented into CES. The focus was on the manufacturing and recycling of the console. The environmental impact during use would only be a rough estimation since there are no exact figures for the needed parameters. The side console can also be seen as a minor contributor to the environmental impact during use, meaning that other parts of the vehicle will have larger contributions. The analysis was done on a fully equipped excavator; meaning that the *Control Module* will contain, 18 rocker switches, 4 knobs and 1 keypad, the *Manoeuvring Module* will however not be included in the analysis since it is designed as a rough estimation of the final module. The results from the analysis are presented in Graph 2, Graph 3 and Table 8.



Graph 2. The energy consumption of the side console.



Graph 3. The CO^2 emissions from the side console.

Phase	Energy (MJ)	Energy (%)	CO2 (kg)	CO2 (%)
Material	1.07e+03	92.2	56.2	89.4
Manufacture	83.5	7.2	6.16	9.8
Transport	0	0.0	0	0.0
Use	0	0.0	0	0.0
Disposal	7.53	0.6	0.527	0.8
Total (for first life)	**1.16e+03**	**100**	**62.8**	**100**
End of life potential	-883		-47.2	

Table 8. Summary of the environmental impact.

The analysis shows that most of the impact will come from the choice of materials while only 7,2% of the energy consumption and 9,8 % of the CO^2 emissions comes from the manufacturing. The side console is presumed to be recycled at the end of the lifecycle, this will reduce the environmental impact, which can be seen in Graph 2, Graph 3 and Table 8, the full analysis can be found in Appendix H. There has not been any comparison with the current side consoles since the data for these consoles could not be collected.

8.4 Cost

The manufacturing cost of the side console has not been calculated in this thesis. Since this would require sending the CAD files to one of Volvo CE's sub-contractors. Who not only would have to calculate the cost of manufacturing the side console but also the cost of the tools needed. There is also a problem with the gathering of the costs of the current side consoles since these in most cases are developed by sub-contractors or a third party manufacturer. Furthermore, there has only been developed one *Manoeuvring Module* for the excavator, a full side console would have modules for the other vehicles as well. The developed side console might not have a lower manufacturing price than the current side consoles individually. However, the cost of the side console compared to all of the consoles that it is meant to replace will most likely be lower. This is due to that it will limit the need of unique components that are required for the current consoles. The console can also be developed in larger quantities then the current consoles since it can be used in all vehicles and for both right- and left hand side. The cost for part numbers will be reduced as well as the total manufacturing cost due to the standardised interfaces on the console. The commonality and modularity theory states that an increasing of these two factors will lead to lower production and product development costs, according to Muffatto and Roveda (2002). These factors lead to the assumption that the development of a modular side console will lead to lower cost regarding both manufacturing and product development for Volvo CE compared to the existing solutions.

8.5 Prototype

From the design a rapid prototype was manufactured. This was done by SLS in order to get the strength needed for the prototype to be self-supporting. The main purpose of the prototype was to validate the overall design with focus upon the modularity and adjustability. Therefore, was just one side console manufactured with the argument that due to its high level of symmetry both left and right hand side could be tested with the same side console. Included modules in the prototype were:

- *Seat Module*
- *Adjustment Module*
- *Support Module*
- *Armrest Module*
- *Casing Module*
- *Manoeuvring Module*
- *Control Module*
- *Stability Module*
- *Safety Module*

The modules where than assembled to a final product, see

Figure 75. Before starting to analyse the modularity and adjustability the common issue with strength from rapid prototyped parts was discovered. Since some parts, e.g. the casing support, are going to be manufactured from bent steel, the SLS part could not represent the strength of these parts as well as it could with the thicker casted parts, e.g.

the adjustment module. The opposite could be said for the lighter parts, e.g. the armrest, which became heavier and more robust than the real part.

Figure 75. Photo of the final prototype.

Once the prototype was assembled if was clear that the requirements stated for modularity and adjustability were fulfilled. Regarding modularity the prototype showed that the properties seen in the CAD was still valid for the prototype. It is possible to change or replace the parts with no major effort or complex tasks. The modularity was also proven to be as expected when it comes to symmetry. The prototype was able to be used on both sides with the slight modification of switching the control module and two of the casing parts to the other side, see Figure 76.

For the adjustability it was shown that all the levels of adjustability demanded by the design were fulfilled. Some issues where found with difficulties adjusting the control module along the base model. However, these are due to that the design of these parts has been with focus upon the possibilities of adjustment and not a detailed solution. The same could be said for the adjustment of the support module; where a detailed solution has to further develop a locking mechanism for locking the parts in place. During the design of the adjustment module it was decided that a resolution of 7 degrees for the tilting. This was evaluated by the prototype and the result was that 7 degrees is sufficient but it would preferably be slightly less. This is however something that needs to be evaluated by operators testing it.

Figure 76. Photo of the final prototype of the side facing the operator.

9 Discussion

The discussion chapter will cover the authors' opinions regarding the results and product development process.

The final design of the side console and the prototype fulfils the needs set by users and Volvo CE. There is future work to be done to the implementation of other vehicles than the excavator but the interfaces have great potential for this implementation. A main issue that was addressed by the operators was the adjustment of the console and the new side console allows adjustment in all translations and rotations demanded by the costumer. The standardised interfaces of the console will also allow Volvo CE to continue the development of new modules. The prototype showed that the final design will fulfil the needs gathered during the research and analysis of the thesis.

The group believes that the *Generic Product Development Process* allowed a good approach for this thesis. Combining the process with the *Product Development Funnel* allowed a good visualisation of the process and clarification of the steps that had to be done at each stage.

Before starting this thesis the knowledge regarding construction equipment vehicles was limited. The research and analysis stage of the project allowed the team to gain knowledge at a fast rate which resulted in a steep learning curve at an initial stage of the thesis. The research and analysis stage resulted in the basis of the thesis regarding customer needs and market knowledge. Initially there were some difficulties with the interviews since the operators were eager to speak about all different parts of the vehicles. This was however something positive for the group's knowledge regarding the vehicles. The negative aspect of theses interviews were that the aspects of the side console received limited space in the interviews. This meant that the group had to restructure the interviews slightly so that the questions focused even more on the side console while still keeping the interviews semi structured. This might have made the interviews slightly too structured but it was something that had to be done to focus the interviews to the aspects of the side console rather than the whole vehicle.

The benchmarking against other brands was not conducted the way recommended by theory since it mostly was done by inspections of the manufacturers brochures. It was decided that the focus during the research and analysis stage should be on user interviews rather than benchmarking the competitors and similar markets while still including these aspects. Since Volvo CE dominates the market and that there are a limited number of retailers for agricultural vehicles and construction equipment in the Göteborg region it would require too much time to visit the retailers of the different brands. Using brochures for the benchmarking meant that the group could only examine pictures taken by the producers of the vehicles who are keen to make their vehicles look as good as possible. Hands on benchmarking approach would allow a more critical and probably more honest result in the benchmarking. It was also difficult to see whether the consoles in the vehicles where modularised or not. The group do however feel that the prioritisation of user interviews was the right approach for the thesis since the solution for the side console should be based on the customer’s needs.

The house of quality had a limited influence on the result of the thesis; this was partly since the group found it hard to combine metrics with the customer needs. The method was however useful for the weight in the *Pugh Matrix*, even though it might not have been used as intended it did play a part in the results of the final design.

The concept generation phase resulted in great creativity from the group with many possible and impossible concepts. There is a problem with only being two persons in a creative stage of a project since it is easy to get stuck in a line of thinking. Using several different methods for concept generation allowed the group to use a new approach to the problem even though the concepts generated might not have been of the best quality in some of the methods.

The final design resulted in a modular side console with great potential for further development and implementation of future technology and needs. The side console could be implemented in today’s vehicles but would also be possible to adapt for the needs of the future vehicles, because of its standardised interfaces which allows for both Volvo CE and aftermarket companies to implement new parts. The design phase of the project was used to decide the detailed solutions for the console. When entering the final design phase there was only a conceptual solution to base the design work upon. The final design took shape via discussions and evaluation in Catia. This might not be the ultimate approach of the detailed design but on the other hand, there has to be changes while designing in CAD. Allowing the design to take form in CAD makes it easier to visualise the concept and by that see any possible problems.

Since the side console is modular, it was easy for the group to work on separate parts in parallel and unite the parts with the standardised interfaces. A current excavator was used as a reference to provide the needed surfaces for the CAD design. This made it possible for the group to adapt the design to the excavator, which was of great importance since the excavator was considered to be the limiting factor. Volvo CE provided CAD-files of a wheel loader as well which made it possible to evaluate the side console according wheel loader. The use of the reference surfaces did however show that there would not be any problems to implement the side console in a wheel loader apart from the *Seat Module* which has to be adapted to each type of seat. Since all vehicles have different seats that have low commonality it was not possible for the group to find a common attachment point for the *Seat Module* which would be preferable.

Almost all modules in the side console are symmetric which means that there will be few part numbers that cannot be used for both sides of the console. This is seen as an important factor for the side console since it will reduce the total cost. Cost was an aspect which as always is important and in this case it should be seen as a operator for the initiative for the thesis. Implementing a modular side console that can be used in the different vehicles will in theory lower the total cost of side consoles. Calculations for the differences in cost between the new side console and the old ones were supposed to be done to enable a comparison between them. However, this was not possible since there were problems with the gathering of cost information for the current consoles and problems with getting a cost proposal from sub-contractors. A proposal of that kind would be an approximation of the cost and also include the cost for starting up the production of the side console. These costs would not be representable for the total actual cost for the side console and since the group was not able to get the costs of the current console it was decided to exclude these parts from the thesis. Instead it was decided to do a comparison from a theoretical point of view.

The purpose of the thesis was to develop a modular side console which could be used in all of the vehicles in the Volvo CE catalogue. One area that was not covered and that should have been included at an early stage is production. The production of the side console has been kept in mind during the work but it has not been the main focus. Including the production department at Volvo CE at an early stage of the project would mean that their aspects and requirements on the side console would have been more apparent. The assembly of the final product, especially the *Control Module*, needs further evaluation by the production department. However it is hard to include all aspects of the development process in the limited time frame given for the thesis and since the production was kept in mind during the process the group felt that the result would be good enough from a production point of view.

The final design consists of few reused parts since the components in the current side consoles differ too much between the different vehicles. The knobs and keypads were used for the new design while the rocker switches were redesigned to a smaller design. The current rocker switches could be used by the implementation of casings that can contain the current rocker switches. This would however lead to limitations in the adjustment of the console.

10 Recommendations

The side console has great potential for further development. The standardised interfaces make further development of modules possible. The console should be adapted to more vehicles by the development of *Manoeuvring Modules* for each vehicle. The excavator has been used as a limiting factor for this thesis; the other vehicles has however been kept in mind during the development to allow the implementation of these vehicles as well.
The seat attachment is a problem that should be addressed for further development. It was not possible during the thesis to find a common attachment point for the *Seat Module*. There are big differences between the seats in the different vehicles and therefore has the *Seat Module* in this thesis been developed only for the excavator. Finding a solution that can be implemented in more vehicles would be of great importance since it would reduce the number of unique parts. The attachment might be possible to do with the use of a “cassette” solution that is mounted over the seat adjustment and suspension. This was however something that was not investigated in this thesis.

The side console will probably not be possible to use with the hydraulic joysticks used in today’s excavator; it is therefore recommended that Volvo CE start developing electric joysticks instead. The electric joysticks would be a more ergonomic solution since they would not cause as much vibrations as the hydraulic and would allow the same level of use as the hydraulic ones. The interviews with the forest machine operators showed that they preferred using the electric joysticks instead of the hydraulic.

The new rocker switches that are designed in this thesis should be used instead of the old ones. The new rocker switches are smaller in size than the currently used which means that they allow more adjustability for the side console. The old rocker switches can be implemented in the side console and the parts needed to do so have been developed. One step further in the development of the *Control Module* would be to implement a CAN bus system which would make the module even more modular and adjustable. The implementation of a CAN bus system was considered in the thesis but it was decided to try to use as much of the current technology as possible.

The locking mechanism for the adjustment of the side console should be further developed so that it allows the user to adjust the console without having to search for the adjustment mechanisms. The adjustability of the side console proved to be an important factor for the users during the interviews and further development of the adjustment mechanism would raise the customer value.

There should be further development of the touch screen concept since it opens up for new possibilities for the users and there work task. Many users have adapted to the use of touch screens in their everyday life and the step into using touch screens in the vehicles would probably not be big for most users. The touch screen could limit the needs of several of the aftermarket products that are implemented in today’s vehicles as well as the need of the *Control Module*.

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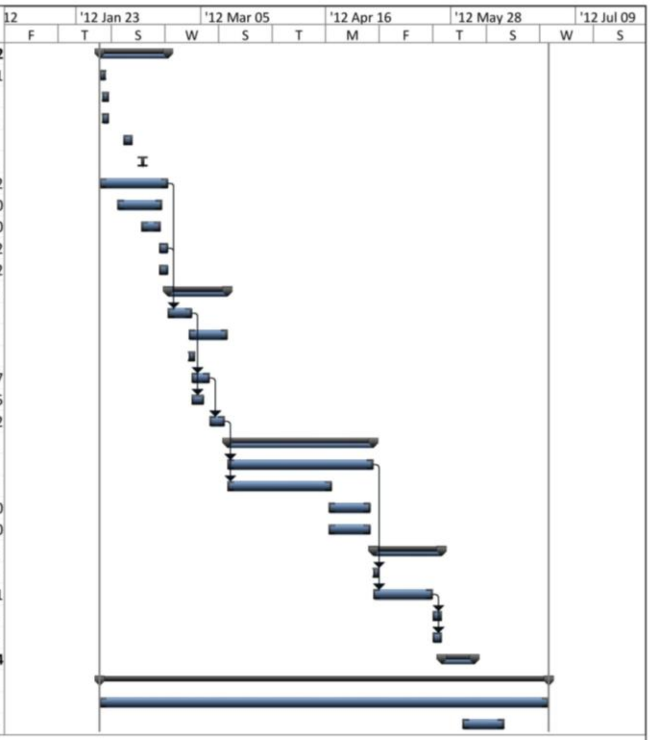
Appendix A Gantt Chart

ID	Task Name	Duration	Start	Finish
1	**Pre-Phase**	**17 days**	**Tue 12-01-31**	**Wed 12-02-22**
2	Planing	2 days	Tue 12-01-31	Wed 12-02-01
3	Define project	2 days	Wed 12-02-01	Thu 12-02-02
4	Difine problem	2 days	Wed 12-02-01	Thu 12-02-02
5	Benchmarking	3 days	Wed 12-02-08	Fri 12-02-10
6	Supplier	1 day?	Tue 12-02-14	Tue 12-02-14
7	User study	17 days	Tue 12-01-31	Wed 12-02-22
8	Funktion analysis	11 days?	Mon 12-02-06	Mon 12-02-20
9	Law investigation	4,5 days?	Tue 12-02-14	Mon 12-02-20
10	Analyse results	3 days	Mon 12-02-20	Wed 12-02-22
11	Literature review	3 days	Mon 12-02-20	Wed 12-02-22
12	**Concept Phase**	**14 days**	**Thu 12-02-23**	**Tue 12-03-13**
13	Idea generating	6 days	Thu 12-02-23	Thu 12-03-01
14	Modularisation	9 days?	Thu 12-03-01	Tue 12-03-13
15	Supplier	2 days	Thu 12-03-01	Fri 12-03-02
16	Material analysis	4 days	Fri 12-03-02	Wed 12-03-07
17	LCA	2 days	Fri 12-03-02	Mon 12-03-05
18	Scetches	3 days	Thu 12-03-08	Mon 12-03-12
19	**Design Phase**	**19 days**	**Wed 12-03-14**	**Tue 12-05-01**
20	Modeling/Developing	19 days	Wed 12-03-14	Tue 12-05-01
21	Integration	14 days	Wed 12-03-14	Tue 12-04-17
22	Ergonomic simulation	5 days	Tue 12-04-17	Mon 12-04-30
23	Calculation/Evaluation	5 days	Tue 12-04-17	Mon 12-04-30
24	**Manufacturing Phase**	**17 days**	**Wed 12-05-02**	**Thu 12-05-24**
25	Supplier	2 days	Wed 12-05-02	Thu 12-05-03
26	Prototype	14 days	Wed 12-05-02	Mon 12-05-21
27	Integration	3 days	Tue 12-05-22	Thu 12-05-24
28	Evaluation	3 days	Tue 12-05-22	Thu 12-05-24
29	**Buffer Phase**	**7 days**	**Fri 12-05-25**	**Mon 12-06-04**
31	**Documentation**	**93 days**	**Tue 12-01-31**	**Fri 12-06-29**
32	Report	93 days	Tue 12-01-31	Fri 12-06-29
33	Presentation	10 days	Fri 12-06-01	Thu 12-06-14



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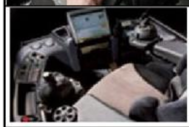
Appendix B Benchmarking

			Ergonomics					Modularity				
	Benchmarking	Brand	Simplicity	Buttons	Rockers	Typ of control	Control complexity	Joystick	Rockers	Buttons	Use of display	Adoption
Excavators		Hitachi	Fairly simple to understand, no organisation among buttons	Everything at the same place, quite close to natural pos of hand	No rockers used, instead buttons together with TS.	Ordinary joysticks	Very simple and the usual user knows how it works				For info together with buttons	
		Komatsu	Fairly simple to understand, no organisation among buttons	Used on a panel together with TS	Just a few of very simple design, strange angle to reach	Ordinary joysticks	Very simple and the usual user knows how it works				For info together with buttons	
		New Holland	Fairly simple to understand, no organisation among buttons	Used on a panel together with TS	A few on the right side, close to the hand but with the strange angle	Ordinary joysticks	Very simple and the typical user knows how it works				For info together with buttons	
		Kobelco	Fairly simple to understand, no organisation among buttons	Used on a panel together with TS	A few on the right side, close to the hand but with the strange angle	Ordinary joysticks but slightly more tilted towards the normal pos of hand	Very simple and the typical user knows how it works				For info together with buttons	
Wheel loader		Hitachi	Very basic layout with few controls	To the left side and quite far from normal pos.	Just one or two mounted on the right side, quite far from the normal pos	Two control system on the right side	Very basic, only forward and backward.				No display	
		New Holland	Many rockers without org. Joystick might not be selfinstructing in a WL	No buttons	All on the right hand side, half of them good pos and the rest to close to the driver + strange angle	Joystick	Very simple but in a vehicle like this it could cause confusion				No display	
		Daewoo	Few rockers, Joystick might not be selfinstructing in a WL	No buttons	A few mounted on the rhs side, strange angle for some of them	Joystick	Very simple but in a vehicle like this it could cause confusion				No display	
Grader		New Holland	For the side consol.									
Trucks		Volvo Trucks	Very basic layout with few controls	No buttons	All arranged on the rhs and with no propper org	-	-				As GPS and modular attached/integrated	
		Scania	Very basic layout with few controls	No buttons	All arranged on the rhs and with no propper org	-	-		Agreed on common module size which makes it possible to costumise the dashboard		As GPS and modular attached/integrated	An agreed modular size should be carried over
		Mercedes										
Agriculture		Case	Very simple layout	Uses some on both joystick and close to the hand	A few for simple functions, Strange angle due to placement to close to driver	Joystick and levers	Fairly simple with a few buttons.				Both info and control, and info with buttons	
		Fendt	A lot of buttons both on joystick and along arm.	Both on joystick and for simple functions along rhs. Some of them could cause strange angles. Clean	Four of them used in an interesting way, good pos.	Joystick. Two types of controls/levers with interesting layout.	The joystick itself has a lot of buttons, though clear layout.				Combination of touchscreen and buttons	
		JCB	Very clean layout. A few buttons on joystick though that makes it a bit more complex.	A few on and around joystick. Good pos.	Four of them used in the same way as Fendt, interesting. Good pos.	Joystick, the same as for excavator.	Quite simple with some buttons in the joystick				Combination of touchscreen and buttons	
		John Deree	A lot of buttons with any clear organization.	A lot of them but located close to the hand, some a bit to close to the driver which could give a strange angle	Just a few for some simple functions.	lever with buttons.	Fairly simple.				Both info and control	
		Massey Ferguson	Relatively simple layout with big controls and rockers	A few for different functions. Good pos close to the hand	Two of them controling simpler functions. Good pos.	Small joystick, simular to harvester.	Fairly simple				Info combinded with buttons	
		New Holland	Simple layout. Clean and easy to understand.	Some on the joystick and a clean solution on the rhs, some of them could cause a strange angle, nice placment under armrest	Four of them in the same way as Fendt and JCB. Good pos.	Two joysticks	One very simple and one more complex with buttons				Both info and control	
		CAT	Small and confusing buttons	Used on both sides and a bit confusing	A few are used on the sideconsole	Small joysticks, much neater than excavator due to operated with the fingers instead of hand	Simpler than excavator				Used for info together buttons	

			Ergonomics					Modularity				
	Benchmarking	Brand	Simplicity	Buttons	Rockers	Typ of control	Control complexity	Joystick	Rockers	Buttons	Use of display	Adoption
Forwarder		EcoLog	Very basic	Used on both sides and a bit confusing	A few on rhs for basic functions	Small joysticks, much neater than excavator due to operated with the fingers instead of hand	Simpler than excavator				Used for info together buttons	
		John Deree	Very complex layout. Intersting pos of joysticks	A lot of them on both sides	Not used	Small joysticks, much neater than excavator due to operated with the fingers instead of hand	Simpler than excavator				Used both for info and control	
		Ponsse Oyj	Simple but a bit messy layout	Used a bit all over the place and some of them with strange angles	Used on the sides for simpler functions	Small joysticks, much neater than excavator due to operated with the fingers instead of hand	Simpler than excavator				Used both for info and control	
Harvester		John Deree	A lot of buttons located around the hands. Interesting pos of joysticks	Used like a keboard, a lot of them and no real organisation	Not used	Small joysticks, much neater than excavator due to operated with the fingers instead of hand	Simpler than excavator				Used both for info and control	
		Ponsse	Relatively simple. Mix of rockers and buttons	Used around the hands close to to the joystick	Used on the lhs for some simpler functions	Small joysticks, much neater than excavator due to operated with the fingers instead of hand	Simpler than excavator				Used both for infogf	
		Sampo Rosenlew	Ralatively simple. Buttons located close to both hand	Located next to joysticks	Located in front of driver and used for simple functions	Small joysticks, much neater than excavator due to operated with the fingers instead of hand	Simpler than excavator				Used for info together buttons	
Crane		Potain	Very clean layout.	a few very simple located close to the hands	Not used	One joystick and one twoway lever or two joysticks	Simpler than excavator				Used for information together with buttons	

Highlights	Brand	Benifits
	-	
	Claas	Rockers are well protected against dust
	-	Rockers are well protected against dust
	-	Clear and easy to clean
	-	Easy to clean

TS = Touch screen
WL = Wheel loader

Appendix C Function Analysis

ED-EC480D (Crawler)	Additional Buttons	Optional	R/L
Remote control radio (Buttons)			L
	Power		L
	Search up		L
	Search down		L
	Select radio		L
	Volume up		L
	Volume down		L
	Mute		L
Attatchen quick coupler switch			L
Audible warning and confirm switch for quick coupler switch			L
Interior light switch			L
Engine limp home switch			L
Automatic/Manual switch			L
Keypad (buttons)			R
	Arrow up		R
	Arrow down		R
	ESC		R
	Select		R
	Rearview camera		R
	Auto idle		R
	Hammer/Shear		R
	Fan speed +		R
	Fan speed -		R
	Airflow direction		R
	Temperature control +		R
	Temperature control -		R
	Air flow circulation		R
	Auto mode selection		R
	A/C		R
	Defroster		R
	HVAC system on/off		R
	Overload warning		R
	Buzzer stop		R
Upper wiper switch			R
Power maximum mode switch			R
Lower wiper switch			R
Washer switch			R

ED-EC480D (Crawler)	Additional Buttons	Optional	R/L
Engince speed / work mode control switch			R
Ignition switch (key)			R
Travel speed switch			R
Working lights switch			R
Extra working lights switch			R
Automatic lubrication switch			R
DPF regeneration sswitch			R
Beacon switch			R
Water separator heater switch			R
Cigarette lighter			R
Power socket (12V)			R
Cup Holder			R
Joystick			R
Joystick			L
Control lockout lever			L

EC - EW210C,EW230C	Additional Buttons	Optional	R/L
Joystick			L
Joystick			R
Light control			L
Control lever for stabilizing leg			L
Atatchment bracket switch			L
Confirm atatchment bracket switch			L
Stabilizing leg front switch			L
Stabilizing leg front switch			L
Interior light switch			L
Stabilizing leg rear switch			L
Stabilizing leg rear switch			L
Travel manual switch (small switch)			L
Auto/Maual switch (small switch			L
Emergency engine speed control switch (small switch)			L
Radio remote control buttons			L
	Power		L
	Search up		L
	Search down		L
	Select radio or cassette/CD/AUX		L
	Volume up		L
	Volume down		L
	Mute		L
Cigarette lighter			R
Temperature sensor for air conditioning			R
Rotating waring beacon switch			R
Automatic lubrication system switch			R
Fuel heater switch			R
Front working light switch			R
Rear working light switch			R
Travelling speed control			R
Mode selector control			R
Right control lever			R
Cup holder			R

EC - EW210C,EW230C	Additional Buttons	Optional	R/L
Lower windscreen-wiper switch			R
Lower windscreen-washer switch			R
Cruise control switch			R
Pivot axle locking switch			R
Engine speed control			R
Ignition switch (key)			R
Fog light switch			R
Electric digging brake switch			R
Rototilt selection switch			R
Power socket (12V)			R
Keypad			R
	Increase fan speed		R
	Raise temperature		R
	Air flow direction		R
	Decrease fan speed		R
	Lower temperature		R
	Air flow circulation		R
	Auto mode		R
	Air conditioning		R
	Defroster		R
	HVAC on/off		R
	Arrow up		R
	Rear vision camera		R
	Escape		R
	Arrow down		R
	Select		R
	Auto idle		R
	Overload		R
	Shut off travelling alarm		R
	X1-tool		R
Control lockout lever			L
Release lever			L

L250G	Additional Buttons	Optional	R/L or other position
Mode selector, gearshifting program (APS III) Control			Post Panel
Regeneration Switch			Post Panel
Fully automatic downshifting (1–4) FAPS Switch			Post Panel
Transmission disengagement Switch			Post Panel
Lock-up Switch			Post Panel
Bucket positioner Switch			Post Panel
Boom kick-out Switch			Post Panel
Hold function, 3rd hydraulic function Switch			Post Panel
Return-to-Dig Switch			Post Panel
Float mode Switch			Post Panel
Single-acting lift function Switch			Post Panel
Spare Switch			Post Panel
Function selector, Boom Suspension System Switch			Post Panel
Switch Switch			Post Panel
Rear work lights Switch			Post Panel
Lighting Switch			Post Panel
Rotating beacon Switch			Post Panel
Electrically adjustable rear-view mirrors Control			Post Panel
Electrically heated rear-view mirrors Switch			Post Panel
Wiper and washer, rear window Switch			Post Panel
Hydraulic emergency stop (Big Button)			Post Panel
Ignition Key			Post Panel
Spare Switch			Post Panel
Rheostat, instrument lighting, guide light in switches			Post Panel
Hand throttle control Control			Post Panel
12 V power socket			Post Panel
Keypad			Behind Stearing wheel
	Esc Button		Behind Stearing wheel
	Engine Button		Behind Stearing wheel

L250G	Additional Buttons	Optional	R/L or other position
	Transmission Button		Behind Stearing wheel
	Hydraulics Button		Behind Stearing wheel
	Arrow up Button		Behind Stearing wheel
	Arrow down Button		Behind Stearing wheel
	Axles /Brakes Button		Behind Stearing wheel
	Electrical system Button		Behind Stearing wheel
	Vehicle information Button		Behind Stearing wheel
	Vehicle message Button		Behind Stearing wheel
	Service Button		Behind Stearing wheel
	Settings Button		Behind Stearing wheel
	Select Button		Behind Stearing wheel
Activating CDC			L
Joystick (steering lever)			L
Kick-down button			L
Directional gear selector Lever			L
Bucket position Lever			R
Bucket tilt Lever			R
Additional Equipment lever			R
Additional Equipment lever			R
Horn Button			R
Control lever lockout Switch			R
Kick Down button on lever			R
Down shifting Button			R
Directional gear selector Lever			R
Activasion Button			R

G990	Additional Buttons	Optional	R/L or other position
Transmission shifter Lever			R
Rheostat, instrument lighting Control			R
Fan speed control			R
HVAC temperature control			R
HVAC air mix and defroster fan Control			R
Air conditioning Switch			R
Lower windows wiper and washer Control			R
Front windshield wiper and washer Control			R
Rear window wiper and washer Control			R
Ignition Key			R
Front headlights and parking lights switch			R
Cab headlights and parking lights switch			R
Front worklights and parking lights switch			R
Moldboard worklights and parking lights switch			R
Upper corner worklights and parking lights			R
Rear worklights and parking lights switch			R
Secondary steering system test switch			R
Hydraulic accumulator switch			R
Heated mirrors switch			R
Extra rear warning beacon switch			R
Single rear warning beacon switch			R
Blade lift lock pin switch			R
Hydraulic control enable switch			R
Auxiliary hydraulic enable switch			Behind stearing wheel
All wheel drive aggression switch			Behind stearing wheel
All wheel drive activation switch			Behind stearing wheel

G990	Additional Buttons	Optional	R/L or other position
Transmission mode switch			Behind stearing wheel
Engine mode switch			Behind stearing wheel
Throttle mode switch			Behind stearing wheel
Throttle control switch			Behind stearing wheel
Differential lock/unlock switch			Behind stearing wheel
Four-way hazard flasher switch			Behind stearing wheel
Keypad			Behind stearing wheel
	Engine Button		Behind stearing wheel
	Transmission Button		Behind stearing wheel
	Hydraulics Button		Behind stearing wheel
	Service meter Button		Behind stearing wheel
	Electrical system Button		Behind stearing wheel
	Arrow up Button		Behind stearing wheel
	Arrow down Button		Behind stearing wheel
	Setup Button		Behind stearing wheel
	Select Button		Behind stearing wheel
	Auxiliary 2 Button		Behind stearing wheel
	Auxiliary 1 Button		Behind stearing wheel
	Escape Button		Behind stearing wheel

A40F	Additional Buttons	Optional	R/L or other position
Electrically controlled rear-view mirrors Switch			Front Left
Headlights Switch			Front Left
Front work lights Switch			Front Left
Rear work lights Switch			Front Left
Rotating beacon Switch			Front Left
Dimmer			Front Left
Electrically heated rear-view mirrors Switch			Front Left
Emergency stop Button			Front Right
Ignition Key			Front Right
Cigarette lighter			Front Right
Regeneration Switch			Front Right
Increased engine speed Switch			Front Right
Delayed engine shut-down Switch			Front Right
Electrically heated seat Switch			Front Right
FS-system Switch			Front Right
Hazard flashers Switch			Front Right
Keypad			Front Right
Engine brake Switch			R
Gearshift lock-out Switch			R
Gear selector Lever			R
Extra hydraulics Switch			R
Windshield wiper rear Switch			R
Parking brake Switch			R
Load and dump brake Button			R
Dump lever			R

Appendix D Module Analysis

Mudule			Type	Affected Model	
Level 1	Level 2	Level 3			
Base	Control		Buttons	All	
			Rockers	All	
			Info screen control	WE CE WL G AH	
			Control wheels	All	Possibility to mount on left side for WE and CE
			Mirror adjustment	WL CWL G	
			Emergency switch	WL CWL AH	
			Key	All	
			Power socket	All	
	Maneuvering		Hydraulic joystick	WE CE CCE WL CWL BHL	
			Electric joystick	WE CE CCE WL CWL BHL	Future idea
			Monkey head	WL	
			Electric lever	WL AH	
			Joystick + lever	CWL	
			Grader control	G	Future idea
			Lever module		
		Lever module			Possibly
	Lever		Support leg/Blade	WE CE CCE BHL	
			Gear	AH	
	Left Maneu.		Steering control	WL CWL	
			Joystick	WE CE CCE BHL	
		Safety	Safty boom	WE	
	Armrest		On seat	WE CE CCE CWL AH G	
			On sideconsol	WL	
			Wrist support	CWL CCE	
	Cup holder		Cup holder	All	Possibly level 1 modules
	Display		Display	WE CE WL LC G BHL AH	
	Seat		Seat attachment	All	

Appendix E Specification of Requirements

Specification of Requirements Side Console Construction Equipment				
Category	**Reference**	**Description**	**Requirements/ Wishes**	**Verification method**
Performance	**SC-PE-01**	Include all the functions represented in todays modells	R	Function analysis
	SC-PE-02	Possibility to connect phone to the integrated audio system in the cabin	W	
	SC-PE-03	Sufficent power supply in the cabin	R	Customer validation
	SC-PE-04	Possibility to have the same function at a number of places	R	Function analysis
	SC-PE-05	Similarities between modells	R	Function analysis
	SC-PE-06	Manage 240days/year in 5 years	W	
Modularity	**SC-MO-01**	Modular interface	R	DSM
	SC-MO-02	Simplicity when adding functions and parts	R	DSM
	SC-MO-03	Simplicity when removal or replacement of functions	R	DSM
	SC-MO-04	A solution that will include all the required functions from the function analysis	R	Function analysis
	SC-MO-05	Position controls and regulators according to the drivers preferences	W	
Ergonomic	**SC-ER-01**	Possibility to adjust the controls and the aperance of them according to the drivers specifications	W	
	SC-ER-02	Symbols that are easy to understand for the driver	R	Customer validation
	SC-ER-03	Possibility to adjust the driver possition according to the drivers specification	R	Customer validation
	SC-ER-04	Possibility to adjust the position of controls and regulators	R	Customer validation
	SC-ER-05	Position of controls based upon the frequency of usage	W	
	SC-ER-06	Position of controls based upon function	W	
	SC-ER-07	Minimized confusion between functions for the driver	R	Customer validation
	SC-ER-08	All regulators and controls shall be reachable without change in posture	R	Ergonomical analysis
	SC-ER-09	Suffient suport for arms, wrist and fingers while operating the controls	R	Ergonomical analysis
	SC-ER-10	A clear status indication of a function	R	Customer validation
	SC-ER-11	The sulotion should not conflict with the way the driver tends to control the vehicle	R	Customer validation
	SC-ER-12	Side console must follow the motion of the seat	R	Test

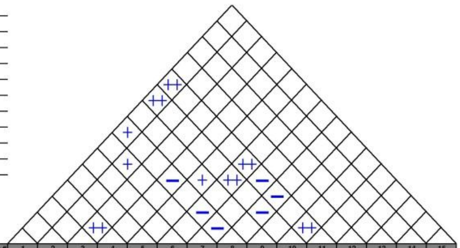
Specification of Requirements
Side Console Construction Equipment

Category	Reference	Description	Requirements/ Wishes	Verification method
Safety				
	SC-SA-01	Not possible to operate the vehicle in incorect position of driver	R	Customer validation
	SC-SA-02	No movement of vehicle when the driver let go of the controls	R	Customer validation
	SC-SA-03	Connecting tools should not alow for any confusion from less experienced user	R	Customer validation
Material				
	SC-M-01	The material used should fulfill Volvos environmntal regulations	R	CES or material test
	SC-M-02	Non flammable	R	CES or material test
	SC-M-03	Non toxic	R	CES or material test
	SC-M-04	Non electrifying	R	CES or material test
	SC-M-05	When shatterd no cuting edges	R	CES or material test
	SC-M-06	Uniforms with the rest of the interior	R	Visualisation
	SC-M-07	Hygenic apperance	R	Visualisation
	SC-M-08	Temperature range -30°C<T<80°C	R	CES or material test
	SC-M-09	UV resistance	R	CES or material test
	SC-M-10	Waterproof	R	CES or material test
Environment				
	SC-EV-01	Lower environmental footprint than the current solution	R	Eco audit
	SC-EV-02	100% energy recyclable	R	Eco audit
Design				
	SC-D-01	A design that does not accumualte dust	R	Test/CAD
	SC-D-02	Give a robust and reliant feeling	R	Customer validation
Maintenance				
	SC-MA-01	Easy to clean	R	Prototype test
	SC-MA-02	Possible to clean with compressed air	R	Prototype test
	SC-MA-03	Possible to clean with wet cloth	R	Prototype test
Production				
	SC-PR-01	Possible to assemble at todays assembly line	W	
	SC-PR-02	Possible to assemble with some modifications to todays assembly line	R	Test assembly
	SC-PR-03	Possible to pre-assembled parts	W	

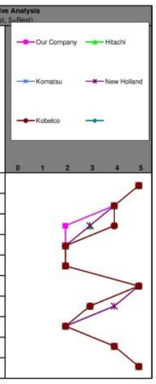
Appendix F House of Quality

Title: Modular Side Console
Author: Gustav Andtbacka, Niklas Dyverfors
Date: 2011-13-16
Notes:

Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	



				Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Competitive Analysis (0=Worst, 5=Best)				
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▲	x	x	x	x	▲	x	x	x	▲	▲									
Row #	**Max Relationship Value in Row**	**Relative Weight**	**Weight / Importance**	**Quality Characteristics** (a.k.a. "Functional Requirements" or "Hows") / **Demanded Quality** (a.k.a. "Customer Requirements" or "Whats")	Modularity	Size	Stability	Robust	Apperance	Commonality	Capacity	Complexity	Hygene	Aftermarket adaption	Customization					Our Company	Hitachi	Komatsu	New Holland	Kobelco
1	9	17,2	10,0	Flexibilility	Θ		O	O				▲		Θ	Θ					5	5	5	5	5
2	9	15,5	9,0	Comfort	O	O	Θ	Θ						O	O					4	4	4	4	4
3	9	5,2	3,0	Easy to clean					O			▲	Θ							2	3	3	3	4
4	9	5,2	3,0	Sufficient Power Supply							O			Θ	Θ					2	2	2	2	2
5	3	12,1	7,0	Support for Arm and Wrist	▲	O		▲						O						2	2	2	2	2
6	3	5,2	3,0	Clear Status Indication of Functions				▲				O			O					5	5	5	5	5
7	3	6,9	4,0	Able to Reach Regulators Without Posture Change		O														3	3	3	4	3
8	9	10,3	6,0	Minimise Confusion Between Grab Lock and Rototillt						Θ		Θ								2	2	2	2	2
9	1	5,2	3,0	Light Switches in Close Reach							▲									4	4	4	4	4
10	3	17,2	10,0	Follow motion of seat			O	▲												5	5	5	5	5
				Target or Limit Value																				
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	4	2	4	4	4	5	5	4	2	3	3									
				Max Relationship Value in Column	9	3	9	9	3	9	3	9	9	9	9									
				Weight / Importance	213,8	103,4	243,1	225,9	15,5	93,1	20,7	131,0	46,6	284,5	263,8									
				Relative Weight	13,0	6,3	14,8	13,8	0,9	5,7	1,3	8,0	2,8	17,3	16,1									



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Appendix G Elimination

Elimination Matrix Adjustment Module					Elimination Criteria (+) Yes (-) No (?) More information is needed **Decision** (+) Pass this stage (-) Eliminated concept (?) Find more information	
Solution	Solves the main problem	Fulfills all the requirements	Ergonomic and Safe	Economically realisable	Comment	Decision
1	+	+	+	+		+
2	+	+	-			-
3	+	+	-			-
4	+	+	+	+		+
5	+	+	+	+		+
6	+	+	-			-
7	+	+	+	+		+

Elimination Matrix Base Module

Elimination Criteria (+)
Yes
(-) No
(?) More information is needed **Decision**
(+) Pass this stage (-
) Eliminated concept (?)
Find more information

Solution	Solves the main problem	Fulfills all the requirements	Ergonomic and Safe	Economically realisable	Comment	Decision
1	+	+	-			-
2	+	+	+	+		+
3	-					-
4	+	?	+	+	Refinement needed	?
5	+	+	+	+		+
6	-					-
7	+	-				-
8	+	+	+	+		+
9	+	-				-
10	+	+	+	+		+
11	+	+	-			-
12	+	+	+	+		+
13	+	+	+	+		+
14	+	+	+	-		-

Elimination Matrix Control Module					Elimination Criteria (+) Yes (-) No (?) More information is needed **Decision** (+) Pass this stage (-) Eliminated concept (?) Find more information	
Solution	**Solves the main problem**	**Fulfills all the requirements**	**Ergonomic and Safe**	**Economically realisable**	**Comment**	**Decision**
1	+	+	+	+		+
2	+	+	+	+		+
3	-					-
4	+	+	+	+		+
5	+	+	+	+		+
6	+	+	-			-
7	+	+	+	+		+
8	+	+	+	+		+
9	+	-				
10	+	+	+	+		+
11	+	+	-			-
12	+	+	+	+		+
13	+	+	+	+		+
14	+	+	+	-		-
15	+	+	+	+		+
16	+	+	+	+		+

Elimination Matrix Screen Module					Elimination Criteria (+) Yes (-) No (?) More information is needed **Decision** (+) Pass this stage (-) Eliminated concept (?) Find more information	
Solution	**Solves the main problem**	**Fulfills all the requirements**	**Ergonomic and Safe**	**Economically realisable**	**Comment**	**Decision**
1	+	+	+	+		+
2	+	+	+	+		+
3	+	+	+	+		+
4	+	+	+	+		+
5	+	+	+	+		+

Adjustment Module					
Pugh Matrix					
Owner:					
Measures|CTQ's|Factors etc.	Importance Rating	**Olskroken**	Angered	Johanneberg	Gårda
Modularity	13		-	-	-
Ergonomics	11		-	-	+
Usability	11		S	S	-
Symetry	5		S	S	S
Adjustability	13		-	-	-
Robustness	10		S	+	S
Flexibility	10		S	S	-
Aesthetics	1		-	-	+
Complexity	5		+	+	-
Future potential	3		S	S	S
Service	2		S	S	S
Cost	9		+	+	-
Simplicity	4		+	+	S
Sum of +'s			3	4	2
Sum of -'s			4	4	6
Sum of Sames			6	5	5
Weighted Sum of +'s			18	28	12
Weighted Sum of -'s			38	38	61
Highest Score Wins			-20	-10	-49

Base Module									
Pugh Matrix									
Owner:									
Measures|CTQ's|Factors etc.	Importance Rating	Excavator console	Storan	Liseberg	Avenyn	Kopparmärra	Synvillan	Feskekörka	Poseidon
Modularity	13		S	S	+	+	+	+	S
Ergonomics	12		+	+	+	+	+	S	S
Usability	12		S	S	+	+	+	S	S
Symetry	6		+	+	+	+	S	S	S
Capacity	10		-	-	+	+	+	S	-
Robustness	10		-	-	-	-	-	S	S
Flexibility	10		S	S	+	+	+	S	S
Hygene	1		S	S	+	+	S	S	S
Complexity	6		-	-	-	-	-	S	S
Future potential	4		+	+	+	+	+	+	+
Service	3		-	-	S	S	S	S	S
Cost	10		-	-	-	S	-	S	S
Aftermarket adaption	5		S	S	S	S	S	S	S
Sum of +'s			3	3	8	8	6	2	1
Sum of -'s			5	5	3	2	3	0	1
Sum of Sames			5	5	2	3	4	11	11
Weighted Sum of +'s			22	22	68	68	61	17	4
Weighted Sum of -'s			39	39	26	16	26	0	10
Highest Score Wins			-17	-17	42	52	35	17	-6

Base Module				
Pugh Matrix				
Owner:				
Measures|CTQ's|Factors etc.	Importance Rating	**Kopparmärra**	Avenyn	Synvillan
Modularity	13		**S**	-
Ergonomics	12		+	+
Usability	12		+	**S**
Symetry	6		**S**	**S**
Kapacity	10		**S**	**S**
Robustness	10		-	**S**
Flexibility	10		+	**S**
Hygene	1		+	**S**
Complexity	6		-	**S**
Future potential	4		**S**	**S**
Service	3		+	**S**
Cost	10		**S**	**S**
Aftermarket adaption	5		**S**	**S**
Sum of +'s			5	1
Sum of -'s			2	1
Sum of Sames			6	11
Weighted Sum of +'s			38	12
Weighted Sum of -'s			16	13
Highest Score Wins			22	-1

Control Module

Pugh Matrix

Owner:

Measures|CTQ's|Factors etc.	Importance Rating	**Excavator button layout**	Älvsnabben	Älvsnabbaren	Gamla Ullevi	Nya Ullevi	Paddan	Andra Långgatan	Frölunda	Hagabion	Vasa Grillen	Glenn	Oldsberg
Modularity	13		+	+	S	S	+	S	S	S	+	+	S
Ergonomics	12		+	+	+	+	+	+	-	+	+	+	-
Usability	12		+	+	+	+	S	+	S	+	+	+	+
Symetry	6		+	+	+	+	+	+	+	+	+	+	+
Kapacity	10		+	+	+	+	+	+	-	+	+	+	+
Robustness	10		-	-	-	-	S	S	S	S	S	S	S
Flexibility	10		+	+	+	+	+	S	S	S	+	+	S
Hygene	1		+	+	+	+	+	S	+	S	S	+	S
Complexity	6		-	-	-	-	S	S	S	S	S	S	S
Appearance	4		+	+	+	+	+	+	-	+	+	+	-
Service	3		+	+	+	+	+	+	-	+	+	+	S
Cost	10		S	S	-	-	-	S	+	S	S	S	+
Aftermarket adaption	5		+	+	+	+	+	S	-	S	S	S	S
Sum of +'s			10	10	9	9	9	6	3	6	8	9	4
Sum of -'s			2	2	3	3	1	0	5	0	0	0	2
Sum of Sames			1	1	1	1	3	7	5	7	5	4	7
Weighted Sum of +'s			76	76	63	63	64	47	17	47	70	71	38
Weighted Sum of -'s			16	16	26	26	10	0	34	0	0	0	16
Highest Score Wins			60	60	37	37	54	47	-17	47	70	71	22

Control Module					
Pugh Matrix					
Owner:					
Measures|CTQ's|Factors etc.	Importance Rating	Vagnhallen Majorna	Paddan	Andra Långgatan	Vasagrillen
Modularity	13		S	-	-
Ergonomics	12		+	S	S
Usability	12		S	-	-
Symetry	6		S	S	S
Kapacity	10		S	-	-
Robustness	10		-	+	+
Flexibility	10		S	-	-
Hygene	1		S	S	S
Complexity	6		S	+	+
Appearance	4		S	-	-
Service	3		-	-	-
Cost	10		-	S	S
Aftermarket adaption	5		S	-	-
Sum of +'s			1	2	2
Sum of -'s			3	7	7
Sum of Sames			9	4	4
Weighted Sum of +'s			12	16	16
Weighted Sum of -'s			23	57	57
Highest Score Wins			-11	-41	-41

Touch Screen Module						
Pugh Matrix						
Owner:						
Measures|CTQ's|Factors etc.	**Importance Rating**	**Nordstan**	Järntorget	Håkan	Ebbot	Taube
Layout	6		-	-	S	S
Ergonomics	7		+	S	+	S
Usability	8		S	S	S	-
Customization	6		-	S	S	S
Replace other features	4		S	S	S	S
Adapt new technology	4		S	S	-	S
Future potential	4		S	S	S	S
Aftermarket adaption	4		-	-	-	S
Sum of +'s			1	0	1	0
Sum of -'s			3	2	2	1
Sum of Sames			4	6	5	7
Weighted Sum of +'s			7	0	7	0
Weighted Sum of -'s			16	10	8	8
Highest Score Wins			-9	-10	-1	-8

Appendix H Environmental Analysis

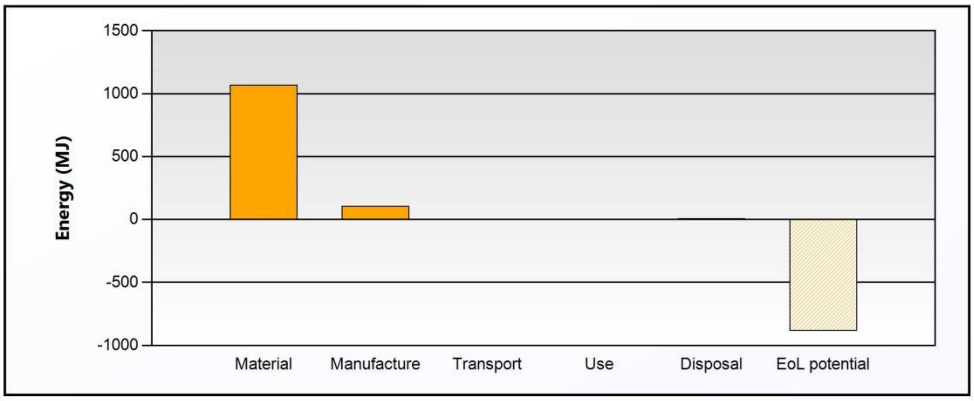
CES 2011 EDUPACK

Eco Audit Report

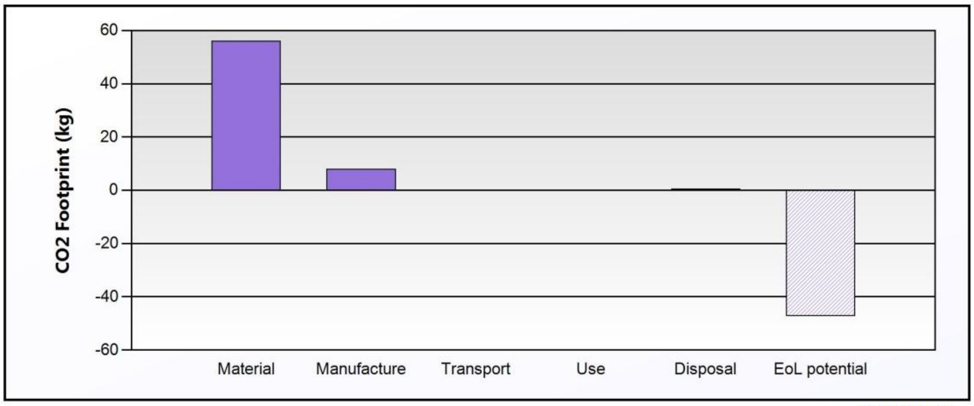
Product Name Modular Side Console

Product Life (years) 1

Energy and CO2 Footprint Summary:



Energy Details...



CO2 Details...

Phase	Energy (MJ)	Energy (%)	CO2 (kg)	CO2 (%)
Material	1.07e+03	90.4	56.2	86.8
Manufacture	107	9.0	7.99	12.4
Transport	0	0.0	0	0.0
Use	0	0.0	0	0.0
Disposal	7.53	0.6	0.527	0.8
Total (for first life)	**1.18e+03**	**100**	**64.7**	**100**
End of life potential	-883		-47.2	

Modular side console.prd NOTE: Differences of less than 20% are not usually significant. See notes on precision and data sources. Page 1 of 11 25 May 2012

Eco Audit Report

Energy Analysis

Energy and CO2 Summary

	Energy (MJ)/year
Equivalent annual environmental burden (averaged over 1 year product life):	1.18e+03

Detailed breakdown of individual life phases

Material:

Energy and CO2 Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass	Energy (MJ)	%
Rocker Switches	Polypropylene (PP)	Virgin (0%)	0.03	17	0.51	48	4.5
Empty Rocker	Polypropylene (PP)	Virgin (0%)	0.014	1	0.014	1.3	0.1
Control Module	Polypropylene (PP)	Virgin (0%)	0.053	4	0.21	20	1.9
Connection module	Low alloy steel	Virgin (0%)	0.05	1	0.05	1.7	0.2
Cemter connection module 1	Low alloy steel	Virgin (0%)	0.21	1	0.21	7.3	0.7
Center conncetion module 2	Low alloy steel	Virgin (0%)	0.1	1	0.1	3.5	0.3
Seat module	Low alloy steel	Virgin (0%)	0.47	2	0.95	33	3.1
Adjustment modules	Low alloy steel	Virgin (0%)	1.3	2	2.7	93	8.7
Support module	Low alloy steel	Virgin (0%)	0.42	2	0.84	29	2.7
Control adjustment module	Low alloy steel	Virgin (0%)	0.042	2	0.084	2.9	0.3
Outer adjustment module	Low alloy steel	Virgin (0%)	0.45	2	0.9	31	2.9
Base Module	Aluminum alloys	Virgin (0%)	1.5	2	3	6.5e+02	61.1
Manoeuvring support module	Aluminum alloys	Virgin (0%)	0.12	2	0.24	52	4.9
Storage module	Polypropylene (PP)	Virgin (0%)	0.064	1	0.064	6	0.6
Stops	Polypropylene (PP)	Virgin (0%)	0.02	2	0.04	3.8	0.4
Armrest module	Polypropylene (PP)	Virgin (0%)	0.16	2	0.32	30	2.8
Base casing module	Polypropylene (PP)	Virgin (0%)	0.15	2	0.3	28	2.6
Center Module 1	Polypropylene (PP)	Virgin (0%)	0.05	1	0.05	4.7	0.4
Center Module 2	Polypropylene (PP)	Virgin (0%)	0.076	1	0.076	7.2	0.7
End Module	Polypropylene (PP)	Virgin (0%)	0.03	4	0.12	11	1.1
Total				**52**	**11**	**1.1e+03**	**100**

*Typic: Includes 'recycle fraction in current supply'

Manufacture:

Energy and CO2 Summary

Component	Process	Amount processed	Energy (MJ)	%
Rocker Switches	Polymer molding	0.51 kg	11	10.2
Empty Rocker	Polymer molding	0.014 kg	0.3	0.3
Control Module	Polymer molding	0.21 kg	4.5	4.3
Connection module	Rough rolling, forging	0.05 kg	0.17	0.2
Cemter connection module 1	Casting	0.21 kg	2.4	2.3
Center conncetion module 2	Casting	0.1 kg	1.1	1.1
Seat module	Rough rolling, forging	0.95 kg	3.2	3.0
Adjustment modules	Extrusion, foil rolling	2.7 kg	17	16.0
Support module	Rough rolling, forging	0.84 kg	2.8	2.6
Control adjustment module	Rough rolling, forging	0.084 kg	0.28	0.3
Outer adjustment module	Casting	0.9 kg	10	9.7
Base Module	Extrusion, foil rolling	3 kg	32	30.2
Manoeuvring support module	Casting	0.24 kg	0.56	0.5
Storage module	Polymer molding	0.064 kg	1.4	1.3
Stops	Polymer molding	0.04 kg	0.86	0.8
Armrest module	Polymer molding	0.32 kg	6.9	6.4
Base casing module	Polymer molding	0.3 kg	6.4	6.0
Center Module 1	Polymer molding	0.05 kg	1.1	1.0
Center Module 2	Polymer molding	0.076 kg	1.6	1.5
End Module	Polymer molding	0.12 kg	2.6	2.4
Total			**1.1e+02**	**100**

Transport:

Energy and CO2 Summary

Breakdown by transport stage

Total product mass = 11 kg

Stage name	Transport type	Distance (km)	Energy (MJ)	%
Total				100

Breakdown by components

Component	Component mass (kg)	Energy (MJ)	%
Rocker Switches	0.51	0	
Empty Rocker	0.014	0	
Control Module	0.21	0	
Connection module	0.05	0	
Cemter connection module 1	0.21	0	
Center conncetion module 2	0.1	0	
Seat module	0.95	0	
Adjustment modules	2.7	0	
Support module	0.84	0	
Control adjustment module	0.084	0	
Outer adjustment module	0.9	0	
Base Module	3	0	
Manoeuvring support module	0.24	0	
Storage module	0.064	0	
Stops	0.04	0	
Armrest module	0.32	0	
Base casing module	0.3	0	
Center Module 1	0.05	0	
Center Module 2	0.076	0	
End Module	0.12	0	
Total	11	0	100

Use:

Energy and CO2 Summary

Relative contribution of static and mobile modes

Mode	Energy (MJ)	%
Static	0	
Mobile	0	
Total	0	100

Disposal:

Energy and CO2 Summary

Component	End of life option	Energy (MJ)	%
Rocker Switches	Recycle	0.36	4.7
Empty Rocker	Recycle	0.0098	0.1
Control Module	Recycle	0.15	2.0
Connection module	Recycle	0.035	0.5
Cemter connection module 1	Recycle	0.15	2.0
Center conncetion module 2	Recycle	0.07	0.9
Seat module	Recycle	0.66	8.8
Adjustment modules	Recycle	1.9	24.9
Support module	Recycle	0.59	7.8
Control adjustment module	Recycle	0.059	0.8
Outer adjustment module	Recycle	0.63	8.4
Base Module	Recycle	2.1	27.9
Manoeuvring support module	Recycle	0.17	2.2
Storage module	Recycle	0.045	0.6
Stops	Recycle	0.028	0.4
Armrest module	Recycle	0.22	3.0
Base casing module	Recycle	0.21	2.8
Center Module 1	Recycle	0.035	0.5
Center Module 2	Recycle	0.053	0.7
End Module	Recycle	0.084	1.1
Total		**7.5**	**100**

EoL potential:

Component	End of life option	Energy (MJ)	%
Rocker Switches	Recycle	-28	3.2
Empty Rocker	Recycle	-0.77	0.1
Control Module	Recycle	-12	1.3
Connection module	Recycle	-1.3	0.1
Cemter connection module 1	Recycle	-5.3	0.6
Center conncetion module 2	Recycle	-2.5	0.3
Seat module	Recycle	-24	2.7
Adjustment modules	Recycle	-67	7.6
Support module	Recycle	-21	2.4
Control adjustment module	Recycle	-2.1	0.2
Outer adjustment module	Recycle	-23	2.6
Base Module	Recycle	-6e+02	67.5
Manoeuvring support module	Recycle	-48	5.4
Storage module	Recycle	-3.5	0.4
Stops	Recycle	-2.2	0.2
Armrest module	Recycle	-18	2.0
Base casing module	Recycle	-16	1.9
Center Module 1	Recycle	-2.7	0.3
Center Module 2	Recycle	-4.2	0.5
End Module	Recycle	-6.6	0.7
Total		**-8.8e+02**	**100**

Notes:

Energy and CO2 Summary

Eco Audit Report

CO2 Footprint Analysis

Energy and CO2 Summary

	CO2 (kg)/year
Equivalent annual environmental burden (averaged over 1 year product life):	64.7

Detailed breakdown of individual life phases

Material:

Energy and CO2 Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass	CO2 footprint (kg)	%
Rocker Switches	Polypropylene (PP)	Virgin (0%)	0.03	17	0.51	1.4	2.5
Empty Rocker	Polypropylene (PP)	Virgin (0%)	0.014	1	0.014	0.038	0.1
Control Module	Polypropylene (PP)	Virgin (0%)	0.053	4	0.21	0.57	1.0
Connection module	Low alloy steel	Virgin (0%)	0.05	1	0.05	0.11	0.2
Cemter connection module 1	Low alloy steel	Virgin (0%)	0.21	1	0.21	0.44	0.8
Center conncetion module 2	Low alloy steel	Virgin (0%)	0.1	1	0.1	0.21	0.4
Seat module	Low alloy steel	Virgin (0%)	0.47	2	0.95	2	3.6
Adjustment modules	Low alloy steel	Virgin (0%)	1.3	2	2.7	5.7	10.1
Support module	Low alloy steel	Virgin (0%)	0.42	2	0.84	1.8	3.2
Control adjustment module	Low alloy steel	Virgin (0%)	0.042	2	0.084	0.18	0.3
Outer adjustment module	Low alloy steel	Virgin (0%)	0.45	2	0.9	1.9	3.4
Base Module	Aluminum alloys	Virgin (0%)	1.5	2	3	36	64.7
Manoeuvring support module	Aluminum alloys	Virgin (0%)	0.12	2	0.24	2.9	5.2
Storage module	Polypropylene (PP)	Virgin (0%)	0.064	1	0.064	0.17	0.3
Stops	Polypropylene (PP)	Virgin (0%)	0.02	2	0.04	0.11	0.2
Armrest module	Polypropylene (PP)	Virgin (0%)	0.16	2	0.32	0.86	1.5
Base casing module	Polypropylene (PP)	Virgin (0%)	0.15	2	0.3	0.81	1.4
Center Module 1	Polypropylene (PP)	Virgin (0%)	0.05	1	0.05	0.13	0.2
Center Module 2	Polypropylene (PP)	Virgin (0%)	0.076	1	0.076	0.21	0.4
End Module	Polypropylene (PP)	Virgin (0%)	0.03	4	0.12	0.32	0.6
Total				52	11	56	100

*Typic: Includes 'recycle fraction in current supply'

Manufacture:

Energy and CO2 Summary

Component	Process	Amount processed	CO2 footprint (kg)	%
Rocker Switches	Polymer molding	0.51 kg	0.82	10.3
Empty Rocker	Polymer molding	0.014 kg	0.023	0.3
Control Module	Polymer molding	0.21 kg	0.34	4.3
Connection module	Rough rolling, forging	0.05 kg	0.013	0.2
Cemter connection module 1	Casting	0.21 kg	0.18	2.3
Center conncetion module 2	Casting	0.1 kg	0.086	1.1
Seat module	Rough rolling, forging	0.95 kg	0.24	3.0
Adjustment modules	Extrusion, foil rolling	2.7 kg	1.3	16.0
Support module	Rough rolling, forging	0.84 kg	0.21	2.6
Control adjustment module	Rough rolling, forging	0.084 kg	0.021	0.3
Outer adjustment module	Casting	0.9 kg	0.78	9.7
Base Module	Extrusion, foil rolling	3 kg	2.4	30.2
Manoeuvring support module	Casting	0.24 kg	0.034	0.4
Storage module	Polymer molding	0.064 kg	0.1	1.3
Stops	Polymer molding	0.04 kg	0.064	0.8
Armrest module	Polymer molding	0.32 kg	0.51	6.4
Base casing module	Polymer molding	0.3 kg	0.48	6.0
Center Module 1	Polymer molding	0.05 kg	0.08	1.0
Center Module 2	Polymer molding	0.076 kg	0.12	1.5
End Module	Polymer molding	0.12 kg	0.19	2.4
Total			**8**	**100**

Transport:

Energy and CO2 Summary

Breakdown by transport stage Total product mass = 11 kg

Stage name	Transport type	Distance (km)	CO2 footprint (kg)	%
Total				100

Breakdown by components

Component	Component mass (kg)	CO2 footprint (kg)	%
Rocker Switches	0.51	0	
Empty Rocker	0.014	0	
Control Module	0.21	0	
Connection module	0.05	0	
Cemter connection module 1	0.21	0	
Center conncetion module 2	0.1	0	
Seat module	0.95	0	
Adjustment modules	2.7	0	
Support module	0.84	0	
Control adjustment module	0.084	0	
Outer adjustment module	0.9	0	
Base Module	3	0	
Manoeuvring support module	0.24	0	
Storage module	0.064	0	
Stops	0.04	0	
Armrest module	0.32	0	
Base casing module	0.3	0	
Center Module 1	0.05	0	
Center Module 2	0.076	0	
End Module	0.12	0	
Total	11	0	100

Use:

Energy and CO2 Summary

Relative contribution of static and mobile modes

Mode	CO2 footprint (kg)	%
Static	0	
Mobile	0	
Total	0	100

Disposal:

Energy and CO2 Summary

Component	End of life option	CO2 footprint (kg)	%
Rocker Switches	Recycle	0.025	4.7
Empty Rocker	Recycle	0.00069	0.1
Control Module	Recycle	0.01	2.0
Connection module	Recycle	0.0025	0.5
Cemter connection module 1	Recycle	0.01	2.0
Center conncetion module 2	Recycle	0.0049	0.9
Seat module	Recycle	0.046	8.8
Adjustment modules	Recycle	0.13	24.9
Support module	Recycle	0.041	7.8
Control adjustment module	Recycle	0.0041	0.8
Outer adjustment module	Recycle	0.044	8.4
Base Module	Recycle	0.15	27.9
Manoeuvring support module	Recycle	0.012	2.2
Storage module	Recycle	0.0031	0.6
Stops	Recycle	0.002	0.4
Armrest module	Recycle	0.016	3.0
Base casing module	Recycle	0.015	2.8
Center Module 1	Recycle	0.0025	0.5
Center Module 2	Recycle	0.0037	0.7
End Module	Recycle	0.0059	1.1
Total		**0.53**	**100**

EoL potential:

Component	End of life option	CO2 footprint (kg)	%
Rocker Switches	Recycle	-0.8	1.7
Empty Rocker	Recycle	-0.022	0.0
Control Module	Recycle	-0.33	0.7
Connection module	Recycle	-0.076	0.2
Cemter connection module 1	Recycle	-0.32	0.7
Center conncetion module 2	Recycle	-0.15	0.3
Seat module	Recycle	-1.4	3.1
Adjustment modules	Recycle	-4.1	8.7
Support module	Recycle	-1.3	2.7
Control adjustment module	Recycle	-0.13	0.3
Outer adjustment module	Recycle	-1.4	2.9
Base Module	Recycle	-33	70.0
Manoeuvring support module	Recycle	-2.6	5.6
Storage module	Recycle	-0.1	0.2
Stops	Recycle	-0.063	0.1
Armrest module	Recycle	-0.5	1.1
Base casing module	Recycle	-0.47	1.0
Center Module 1	Recycle	-0.078	0.2
Center Module 2	Recycle	-0.12	0.3
End Module	Recycle	-0.19	0.4
Total		**-47**	**100**

Notes:

Energy and CO2 Summary