CHALMERS

Optimized Steering Wheel Interface

Designing for Efficient Airbag and Steering Wheel Assembly

MASTER OF SCIENCE THESIS IN PRODUCT DEVELOPMENT

ALEXANDER DRAMOUNTANIS

HENRIK KARLSSON

Department of Product and Production Development
Division of Product Development
CHALMERS UNIVERSITY OF TECHNOLOGY
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Department of Product and Production Development
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone + 46 (0)31-772 1000

Examiner and supervisor: Lars Almefelt

Cover:
The steering wheel assembly illustrated as an exploded computer model, see page 4, Figure 2 for more information.

[Chalmers Reproservice]
Göteborg, Sweden 2010

Abstract

Productivity, efficiency and innovation are just some of the factors a car manufacturer has to respect in order to be successful and keep its competitive edge. When all cars on the market essentially look the same, or works in the same way or even uses the same parts, the smallest details make the difference. Clever solutions and bold design, value for money, fun to drive, this is typical wordplay in the automotive industry to attract customers. The clever solutions are however the most interesting for us. With unique and clever solutions, car manufacturers can excel and be, if not better than everybody else, at least the best that *they* can be. It is a form of internal development, to make the company better, smoother, more efficient. The product development project presented in this report has had the mission to produce such unique and clever solutions. The focus has been on the production of the Volvo Car Corporation steering wheels.

The mission was to make the manufacturing faster, more efficient and ensure the quality of the finished product. This is not an easy task since the complexity of a car makes it challenging to alter or modify one part without other parts being affected. Thus it is always important to have the big picture in mind. For instance it is not only the design or manufacturing issues that need to be respected, there are also issues regarding safety, ergonomics, cost, quality and many other criteria.

The engineering field of product development is however not inexperienced when it comes to meeting these challenges. Car manufacturers alone are dealing with these issues all the time. The problem most apparent for car manufacturers however, are that they rarely change their strategy for meeting these challenges. The companies have their own methods and processes for dealing with all kinds of development work and rarely adopt a unique process for each problem. This is simply too time consuming for companies in this industry. Short development lead times are always crucial in order to get the product on the market in time.

However, working as students in a master thesis project and not using the company procedures, presented the possibility to adapt a unique method and strategy for meeting the challenges of redesigning the steering wheel assembly for the Volvo Car Corporation, thus this project underwent a major exploration of new solutions. The keyword for the process was innovation; to find new solutions and seek new possibilities for how the assembly process could be designed in the future. The solutions then had to be evaluated and refined in order to find the optimal solution that could provide a more efficient and quality-assuring assembly process in the future.

The wide range of different solutions was carefully evaluated to ensure that the final concept met all the requirements stated by the stakeholders of the project. The final concept was an idea of having the entire steering wheel assembly mounted onto the car as a one-piece assembly. A one-piece assembly is a term that has been used in manufacturing for quite some time, it has the intention of integrating smaller parts of a product into a larger assembly piece before it is mounted into the rest of the product system. For the steering wheel assembly this resulted in new interfaces between the parts included. The new solution presented in this project report reduced the number of steps in the assembly process from 11 to only 3 on the production line. The result of this reduction is that it reduces assembly time, personnel cost and the risk of delays in the assembly process. The end result then, thanks to innovative and clever solutions, was a more efficient assembly procedure with a higher level of quality.

Acknowledgements

We would like to thank the following people for their feedback, guidance and confidence in us during the course of this project.

Anders Sandberg	Supervisor, Volvo Car Corporation
Lars Almefelt	Supervisor, Chalmers University of Technology
Venti Saslecov	Group Manager, Volvo Car Corporation
Daniel Bodebratt	Design Engineer, Volvo Car Corporation
Mikael Karlsson	Manufacturing Core, Volvo Car Corporation
Stefan Jansson	System Responsible SWM, Volvo Car Corporation
Richard Biveby	System Responsible Steering Column, Volvo Car Corporation
Thomas Hermansson	Technical Expert Screw Joints, Volvo Car Corporation
Henrik Larsson	Technical Expert Connectors, Volvo Car Corporation
Hans Boström	Technical Engineer, Volvo Car Corporation

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1 INTRODUCTION

This chapter has the purpose of introducing the project prerequisites. The background of how the project came about and the involved parties will be presented together with a stated project objective. A short description of the report outline and a list of some of the abbreviations and terms used in the report will also be presented. Finally, as this is a product development project a section describing the current product which was to be investigated and improved during this project has also been added in this introduction.

The Volvo Car Corporation (VCC) has been seeking to explore new methods for assembling the steering wheel and airbag onto their cars at the production plant in Torslanda, Gothenburg. The current solution has been used for quite some time and has had some problems, for instance there have been quality issues in the form of parts not being properly mounted and electrical cables disturbing the functions of the assembly, which have lead to the need of several control stations on the assembly line to secure the quality. Incremental changes have been made to the products' interfaces which have reduced the number of needed control stations but there is still room for improvement. The incremental changes have had some impact on cost though and there has been a desire to redesign the product and the process of assembling in order to make the process more cost and time efficient and to reduce the number of control stations even further. As a preparation for the launch of a new platform for the steering wheel, VCC recognized the possibility to completely redesign the interfaces and thus a master thesis was presented with this objective. The assembly consists of a number of separate parts and each of them has its own special requirements and regulations that have to be met by the new design. This poses the great challenge of the project, since the assembly touches upon many areas of engineering. Electronics, mechanical properties and customer demands all affect the assembly in some way and all of them have to be respected in the new design.

1.1 PROJECT OBJECTIVE

The assembling of the airbag and steering wheel as it is today is a tedious and perhaps unnecessarily complex operation for the assembly personnel. The method used today requires the steering wheel to be mounted onto the steering column before the airbag can be attached to the steering wheel. It also involves a lot of cables that have to be drawn through the steering wheel to the airbag and these have to be manually put together within small spaces. The cables have further drawbacks since they require special guidance. This special guidance has resulted in an extra plastic cover behind the airbag module with the sole purpose of guiding the cables, this is an expensive solution. The reason for having this cover is to prevent any cables disrupting the anti-vibration properties the airbag module has. In order to minimize vibrations travelling from the engine up to the steering wheel, the airbag has been suspended in a silicone cradle which must not be blocked or disturbed in any way. Without the plastic cover, the cables run the risk of coming in contact with the inside of the airbag and in that way transfer the vibrations from the steering column, making the silicone cradle useless. This guidance results in both additional parts and steps to the manufacturing process. Reflecting on these issues the problem can be defined as follows: To ensure the high quality, control stations have been introduced which have had a negative effect on assembly time and also increased cost. By eliminating steps in the assembly process and at the same time improving the design of the products interfaces, the assembly procedure can become more time and cost efficient whilst at the same time improving or at least maintaining the current quality level, with less control stations.

1.2 Outline of the report

This report will cover the complete project undertaken by the authors at the Volvo Car Corporation during the spring of 2010. The report will follow the process chronologically and explain every step in detail with the theory underlying certain procedures and what was done in practice. This is due to the desire from Volvo Car Corporation to document the method and results of the process for future learning.

Chapter 1 will present the overall project ambition and the problem at hand together with its industrial background. Furthermore the product will be introduced and explained in order to give the reader of this report the necessary information needed to understand the product and project process.

Chapter 2 will discuss what methods and strategies have been implemented during the project work in order to overcome the challenges of the project.

Chapter 3 will present the pre-study that was made in the beginning of the project where the purpose was to investigate the stakeholder needs and to define possible room for improvement in the product.

Chapter 4 will present the overall goals and delimitations of the project which were stated based on the pre-study result.

Chapter 5 describes the process of how the initial ideas and sub-concepts were generated. The chapter will also describe the different sub-concepts in detail and how they were developed further into system-concepts using a morphological matrix.

In Chapter 6 the evaluation of the system-concepts generated during the concept development phase is presented, the purpose of the evaluation was to decide on which system-concepts that were most eligible to be further developed and investigated.

Chapter 7 describes the development process of the chosen system-concepts from the evaluation process. The chosen system-concepts will be described with illustrative computer models and the advantages and disadvantages of them will be discussed.

Chapter 8 will present an evaluation of the system-concepts and which one of them that was chosen to be the final concept and also the motivation of why it was chosen.

Chapter 9 will describe the final concept and its basic functionality with illustrative animated pictures and detailed descriptions of the included parts and features.

Chapter 10 is the final chapter of this report and it will present the overall result of the project outcome together with some discussions and recommendations for future work.

1.3 Terminology and acronyms

The table below presents some terms and abbreviations that are important to be familiar with in order to understand the contents of this report. Abbreviations will also be written out the first time they appear in the text.

VCC	Volvo Car Corporation
SWM	Steering wheel module; holds the electronics for the steering wheel and the levers for indicator signal, windscreen wipers etc.
DAB	Airbag module; complete component with airbag and decorative cover. It also holds the horn function.
Clockspring	Electrical component which has the ability to rotate and is situated behind the steering wheel on the SWM. It connects the electrical parts of the steering wheel with the rest of the car.
Switch packs	The switch packs are situated at the middle spokes of the steering wheel and carry the comfort package for the driver with sound system, cruise and telephone controls.
Deco	Decorative plastic insert on the steering wheel.
SRS	Supplemental Restraint System. The SRS signal is triggered if a car crashes into an object, the SRS signal tightens the seatbelts to pin down the driver or passengers to their seat and then deploys the airbags, all this is done within 20-50 milliseconds.
DFA	Design For Assembly. A method for analyzing assembly processes in terms of ergonomics, efficiency, number of tools and the shape of the parts assembled.
QFD	Quality Function Deployment. A method of translating customer or user needs into measurable requirements.
HoQ	House of Quality. A diagram representing the Quality Function Deployment method used for translating customer or user needs to requirements, the name relates to the shape of the diagram which is similar to a house.
TMU	Time Measurement Unit. A unit of time common in the area of manufacturing for calculating the amount of time it takes to perform certain manufacturing operations. 1 TMU =0,0001 hours = 0,036 seconds
FFF	Free Form Fabrication. A method used to quickly produce prototypes from CAD models. The prototypes are typically made of light sensitive liquid polymer which is hardened with laser to the desired form.
CAD	Computer Aided Design

1.4 Architecture of current steering wheel assembly

Figure 1: Promotion picture of the Volvo S80 interior (www.volvocars.com).

The steering wheel assembly as it is today is illustrated in Figure 1 as a photograph of the finished product and an exploded drawing in Figure 2. The *steering column* is mounted onto the car, connected to the steering mechanism. At the end of the steering column is a conical shaped *steering column pivot* which the *steering wheel* gets attached to. Around the steering column sits the *steering wheel module (SWM)* with the *clockspring*, which transfers the electronic signals from and to the steering wheel, such as airbag signal, indicator signals, windscreen wiper control and more depending on the equipment of the car. The steering column, SWM and clockspring are covered by *two plastic covers*. Before the steering wheel is mounted, the *deco* and *switch packs* are mounted onto the steering wheel. Lastly the *airbag module* is connected to the clockspring with cables and is clicked into place with clips that secures the airbag to the steering wheel.

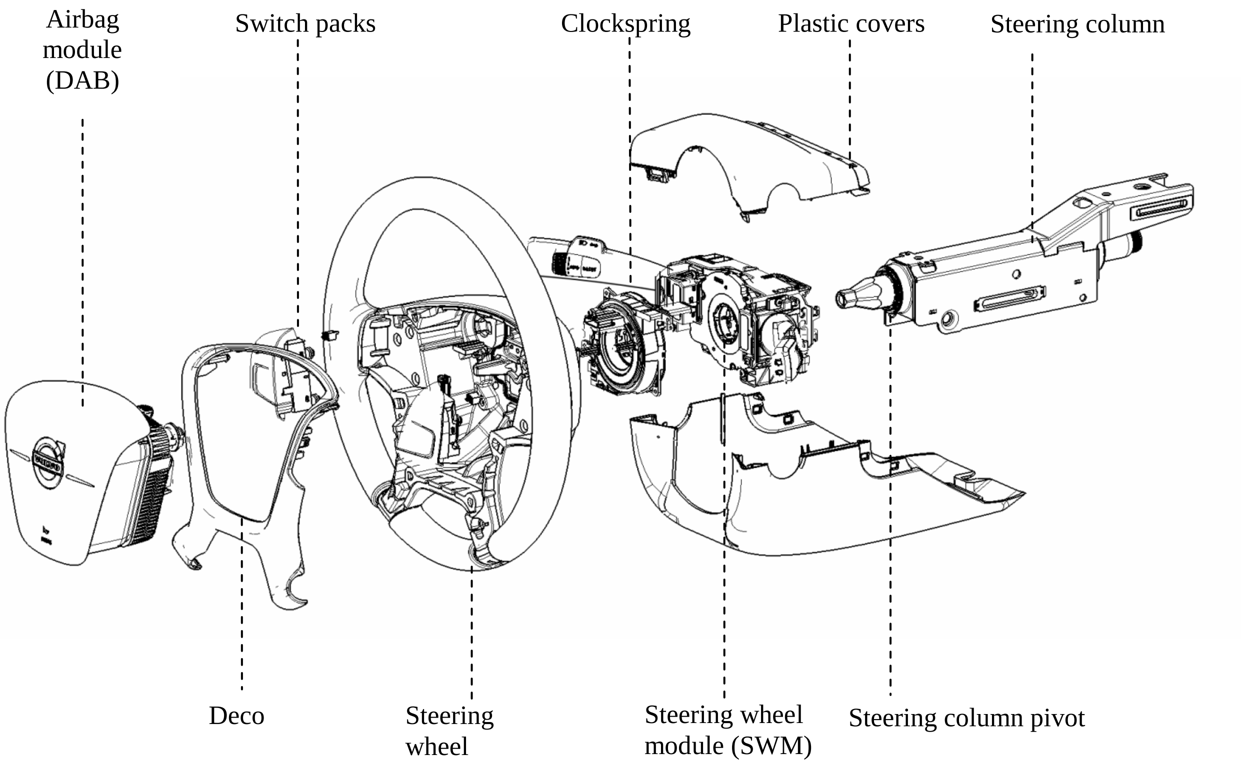
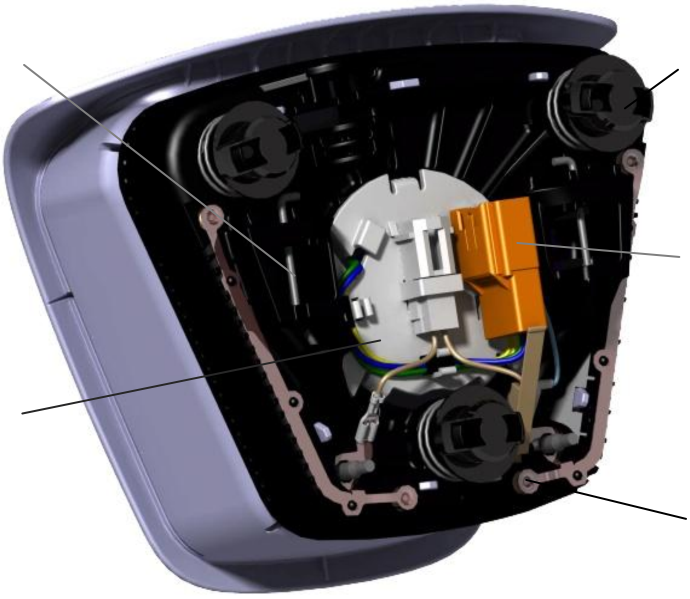


Figure 2: The steering wheel assembly illustrated in an exploded view with the names of the included parts.

1.5 EXPLANATION OF STEERING WHEEL COMPONENTS RELATED TO THE PROJECT

Before the actual project work was started, it was important for the authors to understand the product related to the project. This is equally important for the readers of this report, thus this chapter has the purpose of giving a proper base for understanding how the product functioned and looked like before the development effort was made in this project. The four parts that will be covered mostly in this report are: The airbag module, the steering wheel, the clockspring and the steering column. They are explained in detail below.

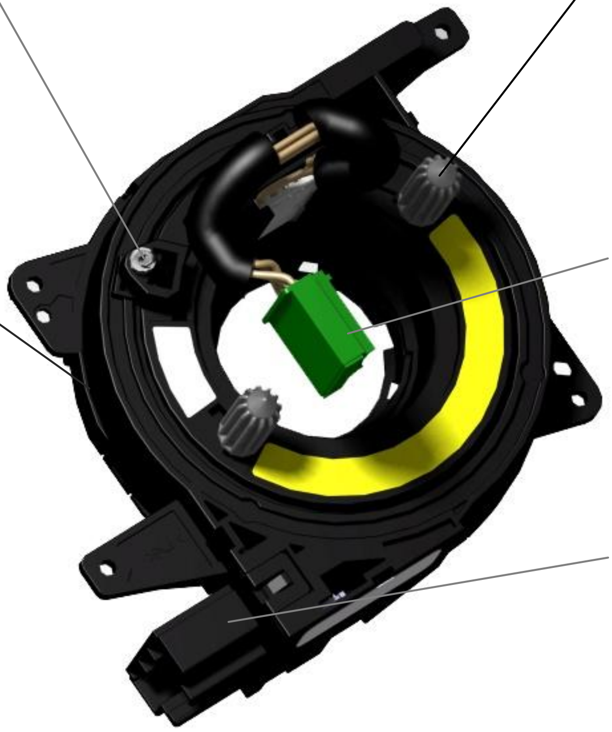


AIRBAG MODULE (DAB)

STEERING WHEEL WITH DECO, SWITCH PACKS AND CENTER LOCKING SCREW

THE CLOCKSPRING LOCKING screw has the purpose of locking the clockspring in its middle position when the clockspring is delivered to VCC. The screw is removed when the steering wheel has been assembled onto the steering column in order to make it possible to rotate the wheel.

THE PART OF the clockspring which does not rotate, the "Casing", is screwed onto the SWM before delivered to VCC. Inside the Casing there is a flat long cable which is winded up in a manner that enables the rotating part of the clockspring to do 3,5 revelations either clockwise or counterclockwise from its middle position. The cable inside the Casing gives the possibility of having power to the steering wheel even when it is turned.



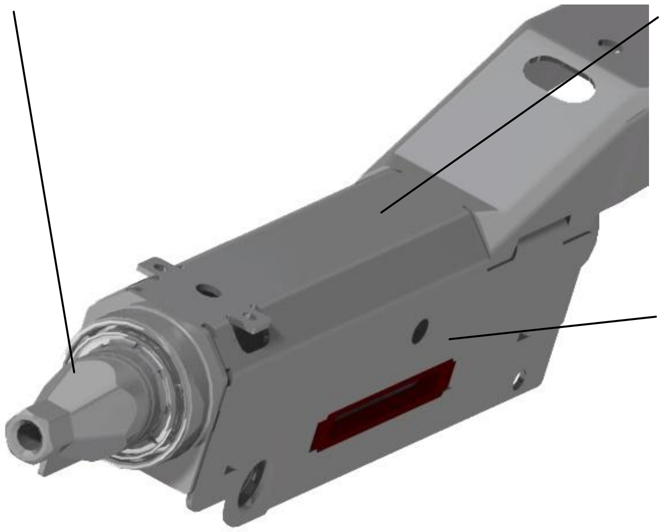
THE ROTATING PART of the clockspring, called "Rotor", features guide pins to accurately attach the steering wheel to the right position in reference to the connector and cables also attached to the Rotor.

THIS CONNECTOR is mated together with the connector situated on the cover plate in the DAB. The connector receives its signal via the flat cable inside the Casing which in turn receives the SRS signal from the SRS connector in the Casing.

THE FLAT CABLE inside the Casing receives the SRS signal from an SRS connector situated on the side of the Casing. The SRS connector resembles the connector situated on the cover plate in the DAB.

THE CLOCKSPRING WITH CONNECTOR TO THE DAB

THE STEERING COLUMN PIVOT has a unique shape in the form of a hexagonal cone. This shape helps to minimize any risk of play between the steering wheel and steering column pivot. The steering wheel has the same shape, only inverted on the backside of it. The center locking screw is inserted in the hole on the steering column pivot when the steering wheel has been mounted and presses the steering wheel onto the conical shape of the steering column pivot.



THE STEERING COLUMN structure incorporates parts that collapse in the event of a frontal collision. The column collapses so that the steering wheel is not pushed up in the drivers face or body during a frontal collision with an object.

INSIDE THE STEERING column structure resides the steering column which is basically a long aluminum tube. The steering column is connected to the wheels of the car through a set of joints.

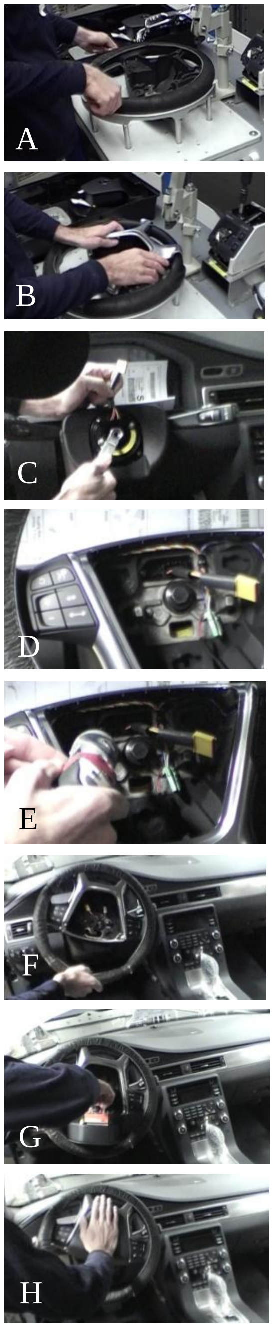
STEERING COLUMN WITH STEERING COLUMN PIVOT

1.6 Assembly procedure for current steering wheel

This chapter will briefly introduce the order of how the steering wheel is assembled onto the car. Table 1 seen below is a simplified version of the one used at VCC to instruct the assembly personnel of the procedures. The tasks that are to be carried out are described in the second column, the third column indicates if there are any tools needed to carry out the task and the final column indicate the Time Measurement Unit (TMU) which is needed to carry out the tasks.

Table 1: Assembly procedure of current steering wheel explained in text and pictures.

	Current assembly tasks/steps	Tool needed	TMU
Pre-assembly (made outside the car)	Place steering wheel in fixture [A]		
	Mount cables for switch packs		310
	Mount switch pack left	Yes	200
	Mount switch pack right	Yes	200
	Secure and fix cables	Yes	340
	Mount deco[B]		330
Pre-assembly total	6 steps		1050
Assembly line (made inside the car)	Adjust steering column [C]	Yes	150
	Bring cables though steering wheel		155
	Mount steering wheel [D]		95
	Place screw		120
	Release locking screw for clockspring [E]	Yes	220
	Move cables		45
	Secure screw	Yes	210
	Turn steering wheel 180 degree [F]		120
	Connect switch packs cables to SWM		165
	Connect cable to DAB[G]		75
	Mount DAB [H]		70
Assembly line total	11 steps		1425
Total	**17 steps**		**2475**



2 PROJECT STRATEGY AND SELECTED DESIGN METHODS

There are many methods and theories available to aid in the structuring of the product development process. This project had its own designed process based on several theories. The purpose of the process was to structure the project in a way that minimizes the risk of late changes which is a common problem in product development projects.

The reason for the many late changes is often the amount of uncertainty which is apparent in the beginning of a product development project, especially if it is a new product development project. If the uncertainties are not minimized in the beginning, unforeseen problems can surface later on in the project when there is too little time to make any changes. It is generally considered that knowledge is increased during the course of a development project but at the same time the design freedom is decreased. Figure 3A illustrates the common knowledge curve with the most knowledge gathered at the end of the project lifetime. Figure 3B illustrates the desired curve where more knowledge have been gathered at the start of the project where there also is more design freedom, the practical method of actually achieving this kind of knowledge curve is often described as "front loading". In practice this means that in the initial stages of the project no real decisions are made regarding the actual designing of the product or system, instead research, analysis and consultations about the product at hand are made. This is a time consuming but cheap process and the benefits can be evident if one really manages to foresee the problems before they appear and in that way eliminate them early on.

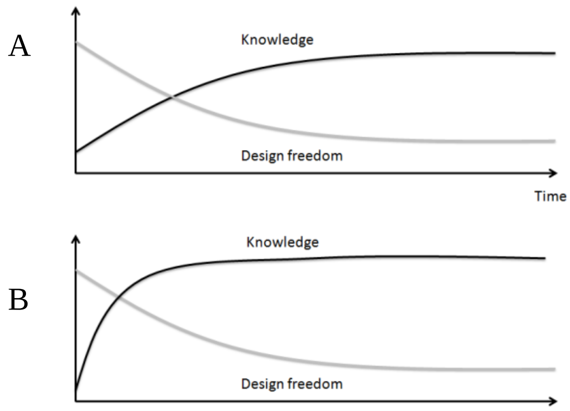


Figure 3: Knowledge versus design freedom development through projects, adapted from (Almefelt, 2009).

Even if the front loading of a project could minimize the risk of delay there are more aspects to consider, for instance focus. Focus is also sometimes described as scope and relates to the zooming in from a big picture to one object. In practice the idea is to have a broad spectrum of ideas in the beginning, and by filtering the scope with different methods the project is more and more focused onto one concept which eventually becomes the finished product. The filtering stages are also called screenings. The impact this have on the possible delay of the project is that the more concepts that are generated, the more time and cost consuming the screening of ideas will be. Thus there is a balance between the amount of time available for the project and the number of concept ideas that are to be generated and developed. There are some known strategies to manage this process and they are commonly related to the business strategy of the company. For instance a smaller company might not have enough time or resources to conduct careful screenings of a vast number of concepts, instead they generate a few concepts and chooses the one they can afford. This method have some benefits in terms of time saving but there are clear disadvantages since it is a great risk to invest in only one concept that have been approved so early on. Worst case scenario is that the concept gets scrapped at the end of the project because of a problem that could have been foreseen if a more careful screening process had been implemented. At the other side of the spectrum there are the large companies with their own Research & Development department. These companies often encourage their engineers to develop as many ideas as possible, even if they might not become realizable. The drawback from this is that there is much resources and time spent on testing out ideas, verifying their impact on the production line and screening of the concepts. This in turn might lead to one good concept in the end but it might have had so much research spent on it that, in the end, it is not even profitable (Wheelwright & Clark, 1992).

Utilizing the theory of screenings, the process illustrated in Figure 4 has been constructed in order to plan the development of the project. The illustration shows how the selection process is supposed to be carried out, smaller spheres represent initial ideas or concepts, whilst bigger spheres illustrates more developed concepts. The screenings are illustrated as oval lenses. The idea is to have as many initial concepts as possible and by having some requirements or elimination criteria at the screenings the less desirable concepts will bounce out from the process or be "killed". When the development of certain concepts becomes more detailed, the spheres grow larger. In the end, after the last screening, it is desirable to have one finished product that has gone through all the criteria and is ready for production. Alternatively it can be accompanied by less developed concepts which support the final concept. This process is often called a funnel process because of its shape.

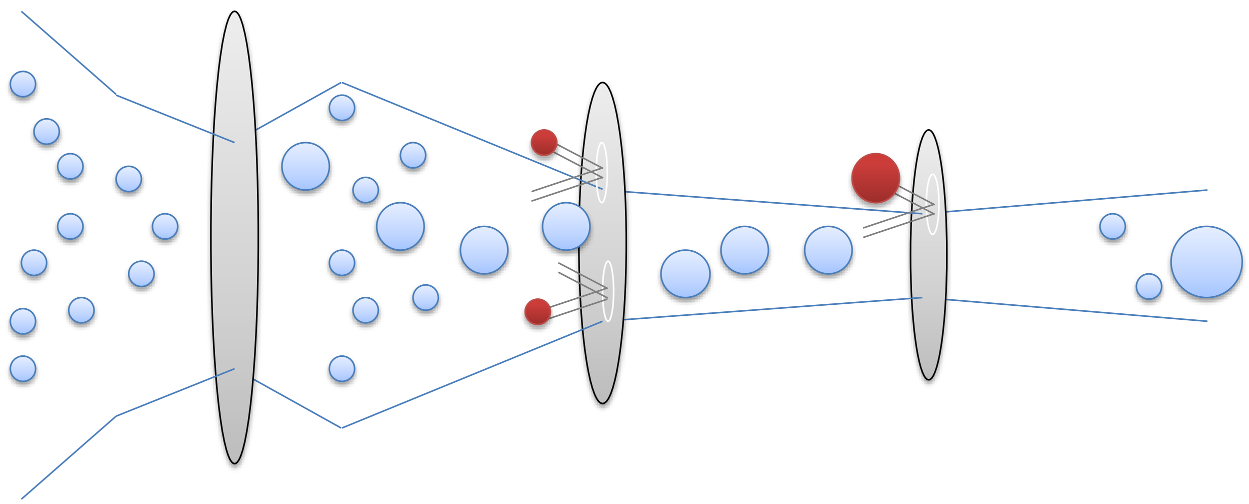


Figure 4: Concept development funnel. The smaller spheres represent initial ideas or concept and the larger spheres represent more developed ideas or concepts. The three lenses represent screening points where the less desirable concepts are killed and only the concepts eligible for further development are let through.

However, the funnel process needs to be more focused and detailed. The screenings for instance are critical points in the development process and needs to be planned well in beforehand. It is especially important to define the criteria which will be used to eliminate the undesirable concepts and it is also important to decide who will make the decisions at these screenings. The stages between the screenings also require some careful planning in terms of what activities needs to be carried out. As a result of this, a Stage-Gate model has been designed, see Figure 5. Stage-gate processes are common in product development projects and used in many companies around the world today. The theory was initially introduced by Robert G. Cooper (Cooper, 1986). The fundamental idea is to have certain stages for a process and Go/No-go gates which the development project has to pass through. For instance a product development project might have a startup stage where information is gathered and the problem is presented, there can also be a proposition of some solution made. After this stage the process reaches a gate point where certain decisions are to be made regarding whether or not the project should go on. If everything is considered alright the project receives a "Go" and carries on to the next stage where new tasks are carried out, if it receives a "No-go", there is either the possibility to redo the previous stage or to kill the project entirely. Table 2 presents the different tasks that were to be made in each stage and the decisions that were to be made at the gates. In this model the gates have been named screenings in order to relate to the funnel strategy which is also eminent in this project process method.

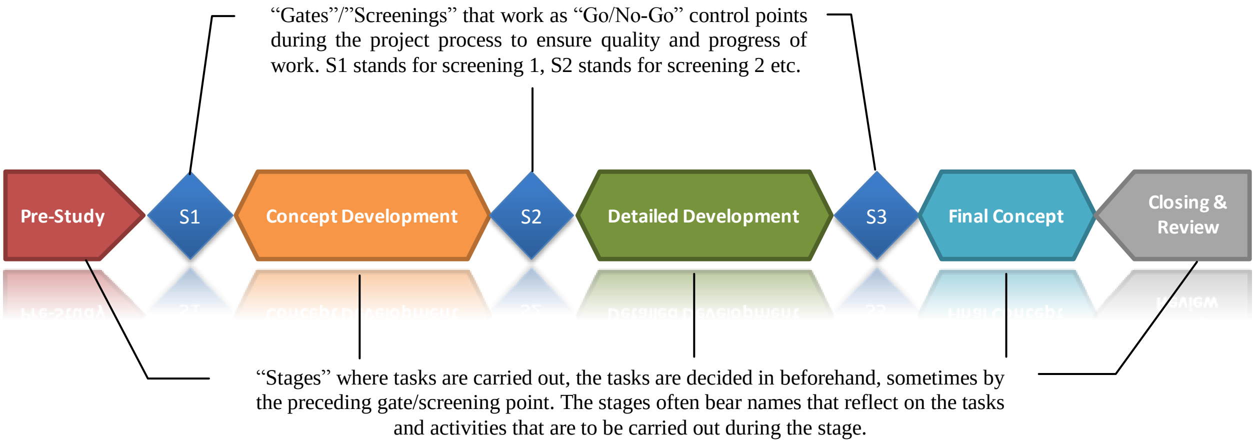


Figure 5: An illustration of the linear Stage-Gate model designed for this project.

Table 2: Project Stage-Gate process, listed with tasks and decision objectives to be carried out in the respective phases of the project.

Pre-Study

- Explore stakeholder demands.
- Investigate product and system structure.
- Interview stakeholders in order to find known problems.
- Define project objective.
- Formulate project goals and delimitations.
- Propose initial changes that needs to be made to the product system.

Screening 1

- Evaluate pre-study results.
- Approve project goals and delimitations.
- Decide on tasks to be carried out in the next stage.
- Decisions are made together with project stakeholders.

Concept Development

- Divide main problem into lesser problems.
- Generate sub-concept ideas.
- Conduct concept elimination process in order to narrow down number of sub-concepts.
- Explore combinations of sub-concepts into complete system-concepts.
- Formulate a proposition of the best system-concepts that can be taken further to the next stage.

Screening 2

- Evaluate system-concepts from Concept Development stage.
- Decide on four system-concepts to release further to Detailed Development.
- Base decision on stakeholder demands and project goals from pre-study.
- Decide on tasks to be carried out in the next stage.
- Decisions are made together with project stakeholders.

Detailed Development

- Translate sketches to 3D models for more detailed design.
- Conduct research on functionality of system-concepts.
- Investigate possibility for mass manufacturing.
- Explore advantages and disadvantages with system-concepts.
- Propose a few number of Final concept alternatives.
- Produce rapid prototype models for verification of functionality

Screening 3

- Evaluate 3D models on aspects of manufacturing feasibility, cost and innovation.
- Decide final concept that will be taken further to Final concept stage.
- Decisions are made together with project stakeholders.

Final Concept

- Refine 3D models and prepare for prototyping.
- Produce realistic prototypes of models for testing.
- Test and verify functionality of final concept prototypes.
- Connect results to project goals and mission statement.

Closing & Review

- Discuss outcome of project.
- Formulate recommendations for further development and mass manufacturing.
- Evaluate Final concept prototype and connect to mission statement and project goals.

3 PRE-STUDY: INVESTIGATION OF STAKEHOLDER NEEDS

The purpose of a pre-study stage is to "think before you do", reverse to a "trial and error" method. There are both advantages and disadvantages with doing a pre-study depending on the magnitude and effort of work put into it. The disadvantages are that there are many uncertainties in the early phase of product development and assumptions made in a pre-study could show themselves to be obsolete or irrelevant when the development finally gets started. The advantages however are that it saves resources, since nothing is built or bought. The purpose is to visualize, observe and recognize: problems that might occur, overall goals and resources allocated for development.

3.1 MISSION STATEMENT

The overall mission statement in terms of stakeholders involved, business goals and constraints is presented in Table 3. A mission statement aids in the decision making process, since it formulates who the primary stakeholders are that will draw advantage or disadvantage of certain decisions. The proposed solutions or ideas should firstly satisfy the primary stakeholders and the key business goals and secondly, as the name implies, the secondary stakeholders.

Table 3: Mission statement formulated by the authors, the method is adapted from (Ulrich & Eppinger, 2000).

Product Description	• Efficient steering wheel to airbag assembly without the use of tools and with fewer steps than current solutions.
Key Business Goals	• Product introduction on market earliest 2013. • Shorten assembly time and thus also lead-time. • Material and manufacturing cost to be reduced. • Maintain or improve level of quality. • The solution must not interfere with customer demands (modularization, variants, options etc.).
Primary Stakeholders	• Engineering design • Assembly staff • Manufacturing engineering • Occupant safety • Frontal restraints • Safety regulations • Finance • Electrical department
Secondary Stakeholders	• Service and after-market • Spare parts • Thieves • End-User (Driver)
Assumptions	• The solution must give feedback to assembly staff. • A snap-on solution could be best. • Airbag and steering wheel is not pre-assembled today.

3.2 Assumed project goals and delimitations

Proposition of goals to achieve during the pre-study and also the overall project, these goals also restrict the scope of the pre-study and will be revised in the end of this chapter as a result of the pre-study´s conclusions when more information has been gathered.

Goals

- The end solution or product should be fully possible to manufacture.
- The new solution should contain fewer parts than current solution.
- Overall costs (time, material, manufacturing) should be lower.
- The solution should enable faster assembly, primarily by removing steps and number. of different tools used in the assembly but also improving interfaces between parts.
- Maintain current level of quality.
- Establish a collection of different solutions, concepts or alternatives for knowledge storing.
- The new solution should be discreet to the end-user (driver) and not give a negative experience in any way such as rattle, noise, flush, gap etc.
- Implement theories, methods and knowledge from the university environment on the working environment and acknowledge the validity of them.
- Minimize development costs.
- Produce a fully functioning prototype for testing and validation of solutions.

Delimitations

- The solution is limited to concern only the following parts: steering wheel, airbag, steering column and clockspring. Not: switch packs and deco.
- The basic functionality of the clockspring module should remain the same but interfaces between clockspring and other modules could be changed.
- Airbag main functionality and abilities should remain the same primarily because of strict safety regulations.
- The solution should use materials that already exist in Volvo Car Corporation´s manufacturing.
- The solution should only implement and/or use technology that is valid in the year 2013.
- Patents could affect which solutions could be used in a market ready product.

3.3 Data collection methods

The methods for data collection used in this pre-study have been inspired by methods and theory from two sources (McQuarrie, 2006) and (Ulrich & Eppinger, 2000). The methods can be divided into three main categories: **documents**, **interviews** and **observations**. Below follows a more detailed description of the three methods and what advantages and disadvantages they may have.

The term "**Documents**" is defined here as both written texts and illustrations. The usage of documents is almost inevitable to a pre-study. Documents that are of most interest are those containing knowledge of the product or problem. It is especially giving to know what have been done in the past and what effects it had on the product. Illustrations of the product, for instance Computer Aided Design (CAD) files can enhance the understanding of the product function and holistic design. Furthermore it is also fairly easy to locate the information you seek by utilizing databases or catalogues etc. to search for keywords related to the requested information. The primary disadvantage with using documents is that it is not possible to discuss the content unless the author is present, which might lead to misinterpretation.

Interviews are complementary to documents. By conducting more informal interviews, more as discussions, useful information can be obtained. During interviews it is important to not be biased and really prepare questions or topics in a proper way. Questions should be open and exploring and not reach for too much specified comments, at least not as initial questions. Follow-up questions can be more specified with the intention of clarifying prior statements by the interviewee. It is also useful to use some form of mediating tools during these discussions or interviews, such as pictures, models or actual products to clarify the interviewees answer and also to create a more comfortable and relaxing environment.

Observations can have different agendas depending on how they are prepared. They can be artificial observations, where the observer creates an environment similar to the actual one of interest. This can have some negative effects on the result since important issues can be overlooked, the sound level in the artificial environment can perhaps be much lower than the actual one and this can be an important factor. Instead of artificial environments the observer can choose to observe by participating in the real environment either actively or passively. Actively in this matter means that the observer takes part in the actual exercise or activity him/herself while passively means that the observer is solely an observer and does not meddle in the activities at all. If the purpose of the observation is to explore behavioral patterns, the passive observer probably gives the best result. Since this method has minimal impact on the ones being observed. The less aware or conscious the observed study objects are, the more reliable the observation will be. In some cases, unconscious behavioral patterns or methods can be used by the study objects which they are not themselves aware of and consequently, those behaviors could not be identified as easily by interviewing the study object. Observations are the best way to find unconscious or unexpected behaviors.

3.4 GATHERED FINDINGS AND ISSUES

As mentioned in Chapter 3.3, the three main forums of data collections have been through documents, interviews and observations. The information gathered from these is presented here in a compiled format.

Interviews were conducted with personnel responsible for different areas of the steering wheel assembly, these included personnel from; manufacturing engineering, assembly, frontal restraints and steering wheel module (clockspring). All of them had some input on all aspects of the steering wheel assembly, however they had different topics of discussion and different interests in what could be changed, improved or developed further with the assembly. No detailed answers from each interview will be presented, instead the answers have been compiled into statements made for each part of the assembly, given the input from all interviewees. Observations were made in the form of filming the assembly personnel when they carried out their normal work procedures. The authors were present merely as observers and did not take part in the assembling. The observations made were compared to the written instructions given to the assembly personnel in order to recognize if there were any differences in procedures. The results of the video observations have also been compiled together with the interview statements to the following findings and issues.

3.4.1 FINDINGS AND ISSUES REGARDING THE AIRBAG MODULE

The airbag has many safety restrictions as it is today. It is crucial that the airbag functionality can be verified already at the assembly station at VCC's manufacturing plant without having to deploy it in any way. For this reason, feedback needs to be given to assembly personnel when they assemble the airbag module in some form. In the current solution, the connectors are mated by hand to the airbag, which gives a distinct clicking sound and feel to the person assembling it. There are also power tools that give visual feedback to confirm that the central steering wheel nut has been tightened sufficiently. Another important issue with the airbag is electrical regulations. The airbag is sensitive to variations in electric potential, so the connectors are of the finest quality (gold plated) and have safety features that prevent the airbag from exploding when it is not supposed to. These safety features are for instance short circuit connectors, which ensure that no static electricity can deploy the airbag when it is not connected to the car. There is an issue regarding the number of connections or "transitions" in the circuit between the airbag and SRS unit which controls the signals to the airbag. It is required that this circuit has as few connection transitions as possible to assure a stable signal to the airbag. In the current steering wheel this requirement has had to be compromised in favor of a solution to another problem. The problem lies within the damping of steering wheel vibrations travelling from the wheels up the steering column. To damp these vibrations, the airbag has been suspended in a silicone hull, which gives the airbag the possibility to move around slightly inside the airbag cover. This solution creates a new problem though, the cables that are connected from the clockspring to the airbag have a slack in them, to enable assembly, and this slack has to be controlled so that the cables do not end up entangled or pinched around the airbag since this could have negative effects on the damping. The current solution is however to add one more connection step between the airbag and clockspring connectors, it consists of a plastic plate with guiding features that controls the cables. This plastic plate increases the cost of the total steering wheel and also adds an additional connection to the SRS-airbag circuit.

Car manufacturers use different solutions for the mounting of the airbag and the vibrations damping. The airbag is sometimes screwed onto the steering wheel or clicked in with clips. The vibration damping can either be done by suspending the airbag in its protective casing like VCC have done or to move the damping outside the airbag completely. VCC has recently gone from mounting the airbag with screws to mounting with clips.

3.4.2 Findings and issues regarding the steering wheel

The steering wheel consists of a combination of materials: magnesium-aluminum alloy, foam, plastic, wood and/or leather. The mix of these materials makes the steering wheel more sensitive to deformations and variations in its dimensions. There have been quality and assembly issues in the past regarding the foam, since some parts of the airbag, which is assembled onto the steering wheel, cuts into the foam and permanently damages it. This could affect the looks of the final assembly in a negative way. Quality checks and testing have identified that it is necessary to have chamfers or guiding features in the foam to minimize deformations when assembling other parts into the foam such as switch packs, deco and airbag. As it is today, the design of the steering wheel allows only a certain order of assembling the different parts onto it. The primary reason for this is to give a higher quality feel to the end-user. The steering wheel has been improved in many aspects in respect to its predecessor, such as assembly complexity and number of parts, but it has had a slightly negative effect on the quality.

Other brands' steering wheels are as different as the cars themselves. It seems thought that the most commonly used way of mounting it to the steering column is by using a screw straight onto the steering column, like VCC has done. Otherwise, the only things differing between different brands are the number of options for extra equipment on the steering wheel they provide.

3.4.3 Findings and issues regarding the clockspring

The clockspring is a central part of the steering wheel assembly, both literally and figuratively. It connects the airbag to the SRS unit which controls the airbag's explosive charge. The main functions of the clockspring is that it should be able to revolve both clockwise and anti clockwise as much as the wheels on the car can allow and then also have about half of a revolution's margin in both directions. It should also be delivered in its middle position so that it is possible for the assembly personnel to assemble the steering wheel in its correct position relative to the clockspring. The current solution incorporates a screw which is tightened to lock the clockspring in its middle position before it is delivered to VCC, the screw then needs to be released when the steering wheel has been correctly positioned. If however the screw is not released, the steering wheel will not be able to turn and this is perhaps not noticed until the very end of the line where the finished cars roll out. The clockspring also needs to be able to lock itself into the middle position again if for instance service personnel need to disassemble the steering wheel for repairs. Today this is done by re-entering the screw which is removed at the assembly line.

There are many variations of clocksprings depending on the supplier but they are all very similar in their function. The things that differ between them are the way they lock the clockspring into middle position and also if they are mounted onto the steering wheel itself or the steering wheel module (SWM).

3.6 Design For Assembly analysis

Design For Assembly (DFA) analysis is a method used to make a product more cost effective and reliable in respect of manufacturing. The idea is to make an analysis of the assembly for each part of a product and especially the assembly operations related to those parts. DFA analysis takes design, production, quality and cost into consideration. The results from such an analysis could be fewer parts and simplified assembly. These two benefits results in lower cost, less purchasing, fewer parts to design, higher quality and shorter assembly time as a few examples. A DFA analysis is typically done with a computer software tool, such a software was used in this project as well. The result of the analysis is a color chart, it can be seen in Appendix A.

The procedure for using the tool is as follows:

- Eight questions are asked for each part during assembly.
- Each question has a number of answers and each answer is worth a specific score.
- Depending on the answers the part gets a score, this score is then added up for all the parts.
- The total score is used by the program to calculate an aggregated score and time, these score can be used as measurement for how effective the product is to assemble.

When all questions have been answered a team can analyze which parts and steps that affect the assembly negatively. The operations with lowest score are to be prioritized for improvement. Those with the lowest score are marked red.

The complete assembly of the steering wheel takes place both outside the car, on a preassembly station, and inside the car. Due to the limitation of this project the most interesting results were those related to the assembly inside the car, since the parts assembled outside were not related to the scope of the project. Both are however important to consider since they add up to the total assembly time. This analysis was also to be used as validation of the new design. See Chapter 10.1 for the result from the DFA of the new design.

The assembly inside the car consists of the following parts

- Clockspring and steering column.
- Steering wheel with deco and switch packs.
- Locking screw for clockspring.
- Cables from switch packs.
- Cables for Airbag.
- Airbag.

The result indicates that the locking screw has a low score on “Need to assemble part” and “Reachability”. The result mirrors the facts that the screw is placed deep in the steering wheel and is hard to see but also that the screw can be replaced with another solution.

The cables for the switch packs and airbag got moderate scores in “Reachability”, “Insertion” and “Tolerance”. The reason is the tight spaces around the cables and the fact that insertion of cables must be precise.

When mounting the steering wheel, especially the fastening and holding of it, got low scores. Due to that a center bolt is used and that the steering wheel is not secured immediately after insertion gives the mounting process a lower score.

The aggregated score for the complete assembly is 74%, where 100% is considered best and 0% worst. The aggregated time is 280 %. A score of 100% means that the assembly has reached its highest potential, a score over 100% means there is room for improvement.

An analysis was also conducted for the assembly made outside the car, the pre-assembly station. This analysis can be of interest for validation of the new design later in the project. The aggregated score was 72% and aggregated time was 253%.

3.7 Quality Function Deployment

The method of Quality Function Deployment (QFD) has the purpose to translate the customer needs, or the customer requirements, into measurable product requirements and criteria. The method provides a foundation to establish requirements that will drive the product or solution towards satisfying customer needs. Below, each step of the process is presented and described following the method proposed by (Ulrich & Eppinger, 2000).

The steps are:

- Identify needs.
- Compile needs to general issues.
- Rank issues.
- Input issues to House of Quality (HoQ).
- Retrieve requirements from HoQ.

3.7.1 Identifying stakeholder needs

Needs are normally formulated by the customer when it is targeted to the end-user. In this case however the end-users are not taken into consideration since they are not to be affected by the development of the product, there are however several stakeholder that will be affected. During the data collection of this pre-study, documents were researched and stakeholders were interviewed and observed. This data could be summarized as a number of statements or observation notes that somehow commented on the current product and suggested both problems with it and positive reactions to it. These statements were translated into needs. An example of this can be seen in Table 4 and the full list can be found in Appendix B.

Table 4: Examples of how the interview statements were translated into needs.

Question/Topic	Interview Statement	Interpreted Need
- Quality	Damping is needed to prevent vibrations traveling from the steering column.	The steering wheel has to be damped.
- Reachability, visibility and feedback	Much easier to assemble outside the car, in terms of visibility and accessibility	All steps, except securing of the steering wheel on the steering column is done outside the car.
- Dysfunctional design or construction issues	Engineering design department have stated that it is impossible to insert the airbag incorrectly, however there have been cases where the airbag is skewed.	It is impossible to assemble the airbag incorrectly. Either it’s done right, or not at all.

3.7.2 COMPILING NEEDS TO GENERAL ISSUES AND RANKING THEM

The method of interpreting needs from interview statements often result in that needs are grouped together based on which physical product they represent or which stakeholder they are important to, this is not desirable. It is of more value to understand *what kind* of needs that are related to the product. For instance one could state questions like; "Are they related to quality issues or manufacturing issues?" and so on. Thus the needs are compiled depending on what kind of issue they represent. After they have been piled into categories, they are given a common heading that describes the issue, these headings do not have to be formulated as a need though. The issues are then ranked with respect to importance. Which one is more important than the other can be difficult to recognize and there is no definitive method. In this case, some conclusions could be drawn from the comments of stakeholders and research, but most of the decision was left to the judgment of the authors carrying out the study. Table 5 presents the list of issues in ranked order, four stars is most important and one star is least important.

Table 5: General issues to attend to during the project which were formulated based on the stakeholder needs.

****	The electrical circuit connecting the airbag to SRS unit must be resistant to disturbances.
****	The fastening and securing of the steering wheel to the steering column is a crucial safety issue.
***	Feedback is needed to ensure build quality.
***	Moving parts within the steering wheel assembly needs to be controlled so that they don't interfere with any functions.
***	Regardless of any design changes to the steering wheel, all functions must be maintained.
***	The new design needs to reduce overall cost and/or assembly time.
***	It should be easy to determine if the assembly has been done correctly or not.
**	Guiding features are needed for fast, easy and correct assembly.
**	The design needs to be adapted to be compatible with future additions to the steering wheel.
**	The new design needs to reduce the number of assembly steps made on the line.
*	The ergonomic aspects of the assembly needs to be taken into consideration.
*	One person alone, should be able to assemble the steering wheel in one complete cycle.

3.7.3 Input to House of Quality

The House of Quality identifies what kind of measurable features can be used to determine if certain needs are met, and also how the needs and features affect each other. In the HoQ, presented in Appendix C, the issues presented in Table 5 have been inserted in the left column (Customer requirements) they have also been given the weight of importance which was translated from the ranking stars. One star was equal to one weight unit. Thus an issue with four stars got the weight of 4.0 etc. When the customer requirements have been stated the next step is to identify what kind of *functional* requirements can be used to measure the customer requirements. The functional requirements should preferably be measurable in some way, such as length, weight, size, score or any other measurable criteria. When these have been identified they are connected to the initial customer requirements in terms of relationship, for instance one measurable criteria can be related to more than one customer requirement and vice versa. Thus these relationships have to be identified as strong or weak relationships. The end result of the HoQ, when all of these steps have been completed, is a ranked requirement list, see Table 6. The ranking depends on three things, how many issues the functional requirements are related to, how strong their relationships are and also the importance of those issues. The end result is a ranked requirement list with each requirement's relative weight of importance and also the desired direction of change. An arrow pointing downwards means a reduction or minimization is desired and arrow upwards means that an increase or maximization is desired. Some requirements has a target value, these values can however not be shown due to confidentiality, instead they are marked with an “X”.

Table 6: Ranked requirement list synthesized from the House of Quality, ▽= Reduce, △= Increase, X = Target value.

Functional Requirements	**Direction of change or target value**	**Relative weight**
Manual connecting operations (#)	▽	8,9
Number of guiding elements (#)	△	8,9
Assembly time (t)	▽	8,7
Number of connectors in circuit (#)	▽	7,1
Pulling force normal to the steering wheel(N)	X	6,7
Length of cable slack (mm)	▽	6,7
Signal input/output variation (V)	▽	6,7
Number of assembly operations outside the line (#)	△	5,9
Evaluation score of functionality (score)	△	5,0
Part manufacturing cost (SEK)	▽	5,0
Ratio between variants and parts (variants/parts)	△	4,3
DFA Score (score)	△	3,9
Ratio between current number of steps and new number of steps in assembly	△	3,5
Input current to steering wheel (A)	X	3,3
Number of audio signals for feedback per operation (#)	X	3,3
Steering column vibration (Hz)	▽	3,0
Total weight (kg)	▽	3,0
Maximum torque on steering wheel (N)	X	2,2
Sound level of audio feedback (dB)	△	2,2
Material cost (SEK)	▽	1,7

3.8 Conclusions of the pre-study

Based on the analysis, certain conclusions could be drawn, these will in turn affect the revised mission statement and project goals to be presented in Chapter 4. Certain assumptions may have been incorrect and certain goals may need redefinition.

The results of the QFD show that the most important requirements to take into consideration involve assembly operations and safety aspects. Also, the top four issues stated based on the interpreted needs covers the same areas.

The DFA analysis shows that there is some room for improvement in certain steps of the assembly. Especially noticeable operations were those related to the clockspring locking screw, handling of cables and the fastening of the steering wheel.

Overall the assembling and construction of the steering wheel is good, especially compared to its predecessor. Some problems have been solved, but those solutions have in turn produced new minor problems or increased cost. Since these solutions have surfaced after the steering wheel was launched there has been little room for major improvements and thus, quick fixes has had to be done.

A one-piece assembly of the steering wheel could be the solution to give higher DFA scoring, reduce the assembly time and improve the quality of the assembly. A one-piece assembly is a term used in assembly and manufacturing process. It refers to the idea of integrating parts that would normally be assembled separately onto a larger product system into a combined part, a one-piece. For the steering wheel assembly this would mean that instead of first mounting the steering wheel and afterwards mount the airbag module in the car, the steering wheel would be mounted with all of its parts already attached to it, including the airbag module.

3.9 Proposition of change to current steering wheel assembly

1. Move assembly of airbag module to steering wheel out from the assembly line (make it a one-piece);
    a. Fastening to steering column needs to be done differently.
    b. Clockspring-to-airbag connection needs to be redesigned.
2. Redesign airbag connection in order to eliminate the use of extra mounting plate for connectors;
    a. Find other solution to secure damping function of airbag.
3. The function of the clockspring "lock screw" needs to be redesigned.
4. Enhance guiding elements and feedback to personnel assembly to minimize the possibility of incorrect assembly.
5. Reduce number of tools used at assembly line.
6. Reduce assembly time.
7. Redesign interface for positioning and fastening the airbag to the steering wheel.

4 REVISED PROJECT GOALS AND DELIMITATIONS

During the first screening, the main objective was to approve that the pre-study had been conducted thoroughly enough. The second objective was to determine the goals and delimitations of the project. This is an important step in the project process since it sets the tone of the rest of the project. It is important to have goals that are reachable and feasible so that the outcome in the end can be measured relative to the goals set in the beginning. In the beginning of the pre-study there were some assumptions made about the goals and delimitations of this project. These assumptions together with the result of the pre-study and consultations with project stakeholders, formulated the new goals and delimitations during the first screening. These goals were to be met by the end result of the project.

REVISED GOALS

- Redesign the interfaces of the assembly to enable a one-piece mounting.
- The end solution or product should be fully able to manufacture.
- Overall costs (time, material, manufacturing) should be lower.
- The solution should enable faster assembly, primarily by removing steps and number of different tools used in the assembly but also improving interfaces between parts.
- Maintain current level of quality.
- Establish a collection of different solutions, concepts or alternatives for knowledge storing.
- The new solution should be discreet to the end-user (driver) and not give a negative experience in any way such as rattle, noise, flush, gap etc.
- Implement theories, methods and knowledge from the university environment on the working environment and acknowledge the validity of them.
- Minimize development costs.
- Produce a fully functioning prototype for testing and validation of solutions.
- The solution should respect the requirements formulated in the pre-study.
- The new solution should be innovative and should not need to respect the requirements or constraints of the currently used solution, instead new requirements should be stated.

REVISED DELIMITATIONS

- The solution is limited to concern only the following parts: steering wheel, airbag, steering column and clockspring. Not: switch packs and deco.
- The basic functionality of the clockspring module should remain the same but interfaces between clockspring and other modules should be changed.
- Airbag main functionality and abilities should remain the same primarily because of strict safety regulations.
- The solution should only implement and/or use technology that is valid in the year 2013
- The aesthetic features of the steering wheel will not be taken into consideration.
- Patents could affect which solutions could be used in a market ready product.

5 CONCEPT DEVELOPMENT

This chapter covers the concept development stage of the project and its different steps. In this stage the general purpose is to generate as many ideas as possible, refine them to some degree and then select the best ideas to develop further.

There are many theories and guidelines available for this stage in the product development process as it is one of the most important ones. However all of these theories and methods have one common goal, it is to structure the chaos of idea generation. It is desirable to have a great number of ideas and concepts in the initial part of a product development process, even bad ones, since these ideas force the developer to really think what can be of value for the project and what does not work. In the end though, one needs to foster something useful from this chaos and derive a few number of possible solutions. In this project, the goal was to have realistic but interesting and innovative solutions at the end of the stage.

The actual process of concept development for this project was fairly structured, first the problem was divided into lesser problem areas to solve, utilizing the method of function analysis. Then, individual sub-concepts were formulated for each problem category. The sub-concepts went through an elimination process, in order to only retrieve the most interesting ones. In the end the different sub-concepts were combined again into a morphological matrix with the purpose of investigating the possibility of different separate sub-concepts functioning together in a complete system. The winners from this morphological matrix were then taken onwards to detailed development where they were refined in order to formulate the final concept. Each of these steps will be explained in detail in the following chapters. An overview of the development process can be seen in Figure 6.

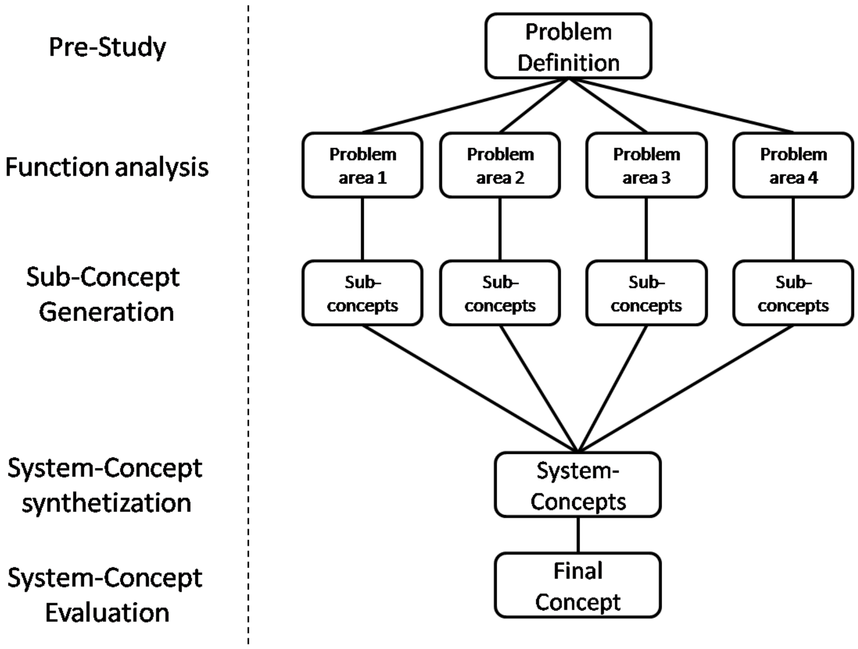


Figure 6: Concept Development Process diagram.

5.1 FUNCTION ANALYSIS OF CURRENT STEERING WHEEL ASSEMBLY

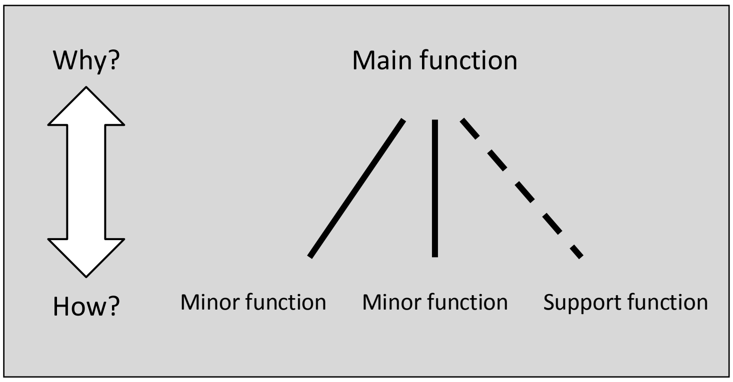


Figure 7: Function tree structure illustration (Österlin, 2003).

Before the idea generation can start it is useful to recognize what problems there are to solve, or which areas to improve in the product at hand. A useful method is to divide the product into the functions that it fulfills. Preferably the main function of the product should be defined first, then sub or support functions that helps to fulfill the main function and so on, see Figure 7. The end result is a function tree with all the products functions structured in levels, depending on their impact on the product's functionality. An easy way to formulate a function is to combine a verb and a noun that best describes the function. The main function of a bread toaster can for instance be described in this way as "Heat Bread". Sub functions to that same toaster could be; "Adjust Heat", "Hold Bread", "Eject Bread" and so on (Österlin, 2003).

This method was applied to the parts of the steering wheel assembly. The main function of for instance the SWM (clockspring) was divided into lesser functions that could be targeted for development. For instance the main function of the clockspring is to "Transfer Signal" thus it is placed at the top of the tree, then moving downwards the branches of the tree, minor functions are found. All function trees can be found in Appendix D. Moving downwards in the tree also answers the question "How?" or rather "How will this function be supported by lesser functions?" while moving upwards towards the main function answers the question "Why?" or rather "Why is this lesser function needed?" see Figure 7. Not all functions were chosen to be developed or improved but some were chosen based on the comments given at the interviews during the pre-study. Functions that either slowed down the assembly time, added cost or affected the assembly negatively in any way were taken further for brainstorming.

In the end, four different main functions or problem areas in the steering wheel assembly were identified as the ones to focus on in order to reach the project goals and these would be treated separately during the brainstorming. The problem areas were:

- Airbag mounting onto the steering wheel
- Clockspring locking function
- Steering wheel securing to steering column
- Signal transfer from SWM and clockspring to airbag module

5.2 SUB-CONCEPTS GENERATION

As is common for a concept generation part of a development project, brainstorming sessions are made to generate ideas. It can however be difficult to know where to start. It is therefore useful to establish some ground rules, prerequisites and also do some research before the brainstorming so that the most benefits are drawn from it. In this project the pre-study was used to establish these prerequisites. Before the actual brainstorming session there was a more general brainstorming regarding the overall product system and how this affected the problem solving. There was a discussion of the goal of the brainstorming or in other words, what kind of scenario the ideas at the brainstorm would aim at fulfilling. In the end it was decided that the actual brainstorming should concentrate on finding ideas making it possible to assemble the steering wheel as a one-piece outside the production line and then secure the whole steering wheel as it is to the steering column with a screw. This scenario was based on the result from the DFA analysis and the conclusions drawn from the pre-study which showed that this idea could reduce assembly time and assembly complexity.

5.2.1 BRAINSTORMING

The brainstorming was done in several steps. First of all there was an internal brainstorming session with only the authors present. The different functions chosen from the function tree analysis was taken into consideration one by one for brainstorming and thus some concept ideas were generated for each such function. At a later stage, combinations of these functions were discussed in order to see if the idea of combining some of them together could foster new ideas. Lastly a brainstorming was made together with VCC staff from different fields of expertise such as Design engineering, Electronics and Manufacturing engineering. The brainstorm sessions were documented by writing and sketching ideas on a board and then taking pictures of it, see Figure 8, in order to compile it to a more organized list later on, the list can be found in Appendix E.

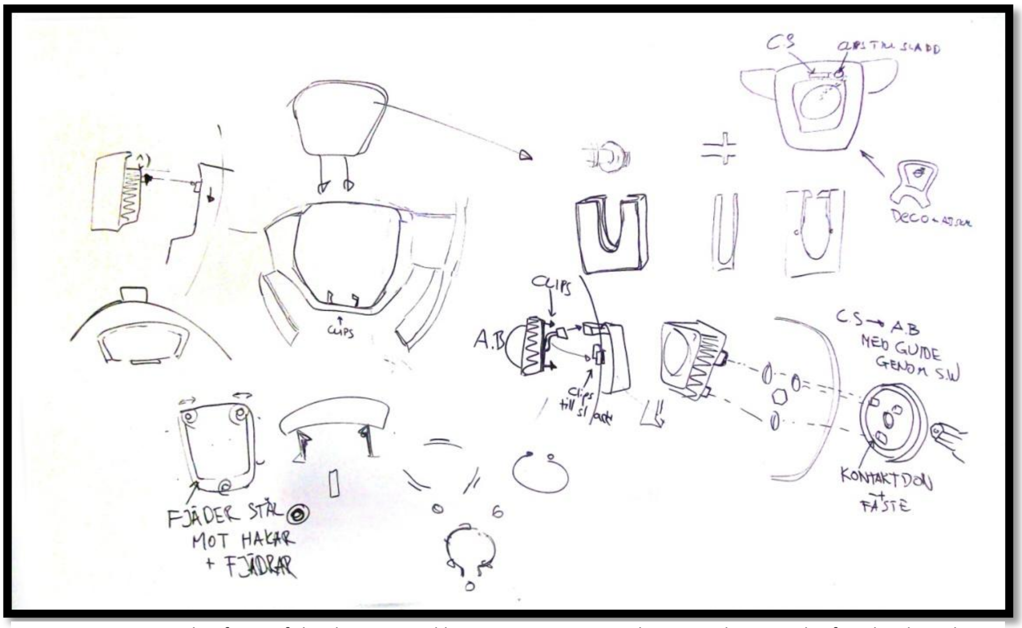


Figure 8: Example of one of the documented brainstorm sessions taken as a photograph of a whiteboard.

5.3 Descriptions of sub-concepts from brainstorming

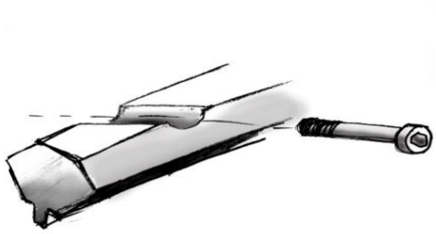
This chapter will briefly present some of the sub-concepts generated during the brainstorming sessions. Not all of them were considered realizable at the time but one of the goals of this project was to save the concept ideas for future projects. Thus they are presented here for future learning. The sub-concepts are presented in random order since they were generated in that way.

Screw airbag from back

Concept idea to screw the airbag onto the steering wheel from the back. This idea enables the airbag to be secured and verified in a definite manner compared with the current solution which is done by clips into the foam structure of the steering wheel. The concept however requires the airbag cover to be mounted with some sort of spring load since there is still the need to have a “floating” airbag cover with a horn function.

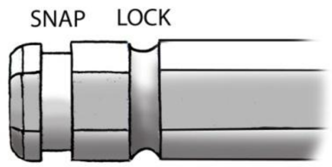
Asymmetric steering column pivot with angled screw.

This concept enables the airbag module to be mounted onto the steering wheel before the steering wheel is secured to the steering column pivot. This is possible since it is screwed from an angle, for instance from underneath the steering wheel or from the side. The angle also provides a mating force between the steering wheel and the steering column pivot in two directions, the two angle components.



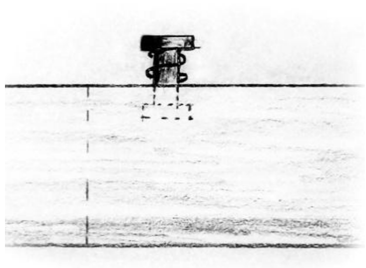
Snap-Lock

A concept primarily developed to enhance the theft protection for the steering wheel. If the steering wheel is to be mounted together with the airbag as a complete “one-piece”, a screw has to be tightened from the side or from underneath. The problem this imposes is that a thief can easily access this screw and as a result can steal the whole steering wheel. However, this Snap-Lock features two grooves, the first one (Snap-groove) is intended to have clips that clicks in place in the first groove when the steering wheel is mounted. The second groove (Lock-groove) receives the screw which tightens the steering wheel into place. This makes the assembly of the steering wheel easy but the disassembly more complicated since one needs to remove the clips around the first groove in order to remove the steering wheel.



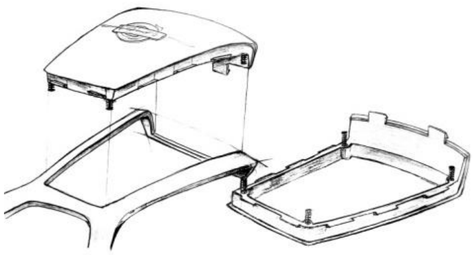
Spring Pin

This is a concept for the locking function of the clockspring. Instead of having a screw which needs to be manually removed in order to release the clockspring the idea is to have a spring loaded pin which unlocks the clockspring when it is pressed in. This pin can be situated on the surface of the clockspring that meets the steering wheel when it is mounted. This results in the clockspring being released only after the steering wheel has been mounted and it is locked again if the steering wheel is removed. This is desirable in the event of service for instance.



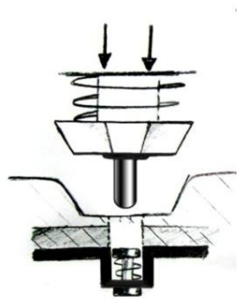
FLOATING AIRBAG COVER

In the case of having an airbag screwed into the steering wheel, there needs to be a new solution to keep the floating airbag feeling for the horn function. This concept represents the idea of having a separate airbag cover which is attached to the deco plastic. The cover is mounted with latches to the deco inner parameter and has spring loaded feet that meet the steering wheel inner base. So, in the case of having the airbag screwed to the base of the steering wheel, the cover and deco is mounted over the airbag and provides a flexible horn function.



PIN IN HOLE

The idea is to have some sort of pin on the steering wheel or even the DAB mounting feet as illustrated in the picture. The benefit of this, apart from the ones discussed in the Spring Pin above is that it is not as easy to accidentally unlock the clockspring in this case since the spring loaded pin is hidden. The concept of having the pin attached to the DAB feet also provides a guiding feature for the DAB when it is mounted onto the steering wheel.

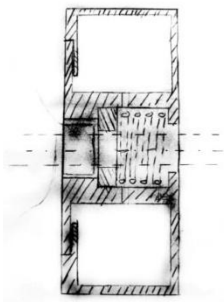


FLEXIBLE CONNECTOR

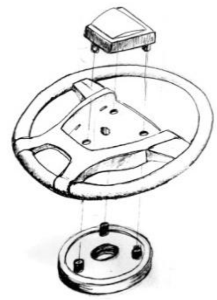
In the current assembly, a plastic plate controlling the cables between clockspring and airbag module has been added to the backside of the DAB. It has been recognized that it is desirable to eliminate this plastic plate in order to lower the total manufacturing cost of the steering wheel. The flexing connector is meant to function as a rigid connector with some flexing abilities. The idea is to have a rigid connector house on the DAB and a flexible mate on the clockspring. When the airbag module is mounted it will automatically mate with the clockspring connector without having to mate the connectors manually as it is done today. The benefits of this will be that there is no extra cable slack needed to mate the connectors together, which in turn means that there is no extra cable that needs special guidance. The cables are instead controlled within the flexing membrane of the connector housing in the clockspring. It has to be flexible in order to support the floating horn function of the DAB.

CENTRUM LOCKING SPRING OF CLOCKSPRING

This is a concept aiming to unlock the clockspring when the steering wheel is mounted onto the steering column. The clockspring incorporates a ring in the centre of it which is spring loaded and locked in its position until it is pressed down by the back of the steering wheel. In the event of service or other disassembly the clockspring is relocked as soon as the steering wheel is dismounted.



DAB TO CLOCKSPRING THROUGH STEERING WHEEL

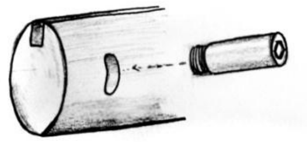


Assembling the DAB to the steering wheel, with the clockspring attached to the backside of the steering wheel. The DAB will connect to the clockspring automatically through the feet which contains connectors, this enable the idea that the DAB will have connection as soon as the DAB is mounted properly.

IKEA SCREW

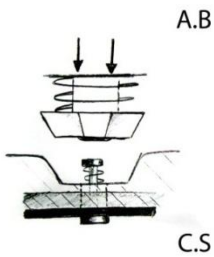
The IKEA screw sub-concept was inspired, as the name implies, by a locking mechanism utilized in certain furniture assemblies. It incorporates a pin, which in this case would be the steering column pivot, and a screw or ring with a gradually increasing thickness. The screw is resident in the steering wheel and when the steering wheel has been mounted onto the steering pivot, the screw is turned almost a complete revelation and thus locks the steering wheel to the steering pivot by squeezing the thicker part of the screw into the groove of the steering pivot.

SCREW THROUGH ASYMMETRIC STEERING PIVOT



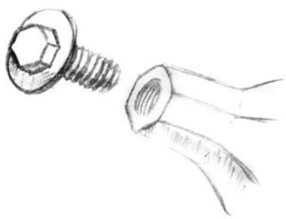
A sub-concept which enables the steering wheel to be mounted onto the steering column pivot with airbag module already mounted in the steering wheel. The asymmetric shape is needed to guide the steering wheel into place correctly so that the screw can be inserted into the hole. Since the hole needs to be somewhat bigger than the actual screw in order to ease assembly operations there is a risk of play in the steering wheel assembly.

DAB FEET UNLOCKING CLOCKSPRING



This sub-concept has the purpose to certify that when the DAB has been mounted into the steering wheel, the clockspring will be unlocked. This provides a sort of assembly confirmation since if the DAB is mounted incorrectly it will not be possible to turn the steering wheel since the clockspring will be locked in its middle position.

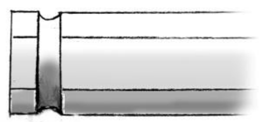
CURRENT SOLUTION FOR SECURING OF STEERING WHEEL



The current solution for the securing of the steering wheel has been included in this list since it was combined with some of the other sub-concepts when synthesizing the system-concepts which will be discussed more thoroughly in the next chapters. It is essentially a screw that goes straight through the steering wheel and into the steering column pivot to secure the steering wheel.

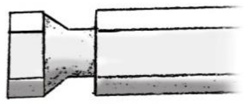
Touching screw

The touching screw sub-concept consists of the steering pivot with a groove at the end of it going all the way around. A screw is inserted in such a way that it resides in the groove. The biggest advantage with this concept is that there are no limits to from which end the screw is to be inserted, since the steering column pivot is symmetric. It can be inserted from the sides, above or below the steering pivot. The steering pivot however needs to be marked so that the steering wheel is attached correctly in reference to the wheels middle position. The disadvantage is however that due to the design of the groove, being completely perpendicular to the pivot, there is a risk of play between the screw and the groove, since the groove needs to have a bit bigger radius than the screw to ensure mating..



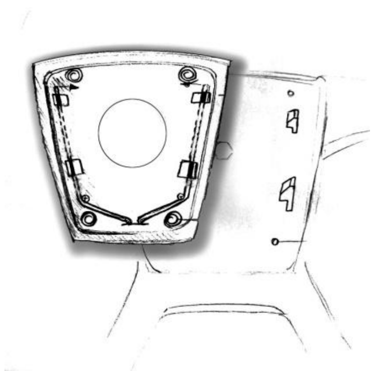
Wedge

The wedge sub-concept resembles the touching screw sub-concept above but has one feature to ensure there is minimal play in the assembly. The screw is inserted somewhat offset from the actual groove, where the groove is more shallow and in the shape of a slope. When inserted, the steering column pivot will be forced to move in relation to the screw as the screw goes further and further in its groove, which results in a squeezing force.



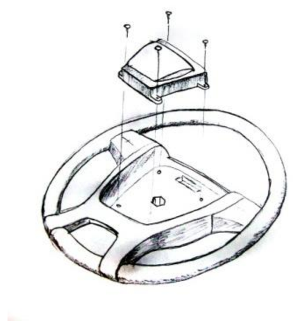
Latches mounting Airbag

This sub-concept resembles the current product, the main difference is that it does not feature any “feet” that will mount it to the steering wheel foam. Instead there are only a set of flexible latches and springs that will click the DAB into place and then provide the flexible horn function through the springs around the sides. The biggest advantage of this sub-concept is that it includes fewer parts than current solution and does not affect the foam. However it needs to be guided well in order to minimize risk of gaps and flush in the assembly.

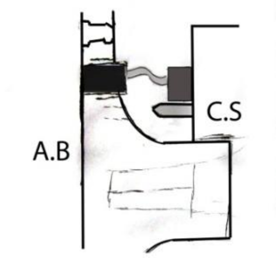


Screw Airbag from front

This sub-concept provides a more secure way of fastening the DAB to the steering wheel than current solution. The DAB is screwed into place which has the advantage that the mounting can be confirmed well with certain tools. The main disadvantage is that it requires more operations at the assembly station and that the flexible horn function needs to be solved in another way than current solution.

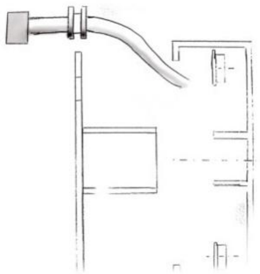


Back facing connector to SWM



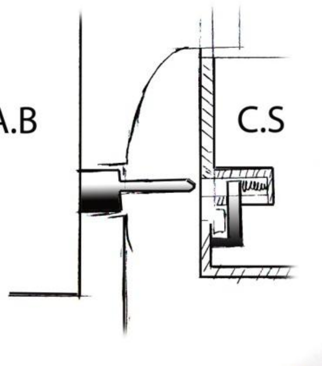
The back facing connector in this sub-concept has the purpose of removing the cable slack in the current solution to the outside of the steering wheel. This means that the DAB will incorporate a connector that will surface on the backside of the steering wheel. When mounted onto the steering column pivot a connector with cable from the clockspring is attached to the DAB connector and the cable slack is then guided and secured between the clockspring and steering wheel.

Straight through cable from clockspring



This sub-concept has the purpose of eliminating connector steps in the circuit between SRS signal and DAB. The idea is to have the flat cable, residing in the clockspring, to go directly into the DAB connector. In the current solution, the flat cable needs to be welded on a transition which transfers the signal from the flat cable through a standard isolated cable to the DAB.

Pin in hole from steering wheel release clockspring



The idea in this sub-concept is to provide an automatic unlocking feature for the clockspring. It incorporates a pin, sticking out from the steering wheel backside, which will be inserted into a hole in the clockspring when mounted. The hole in the clockspring will include a spring loaded plate which is displaced by the pin from the steering wheel and thus, unlocking the clockspring automatically.

Current solution for mounting Airbag "latches and feet"

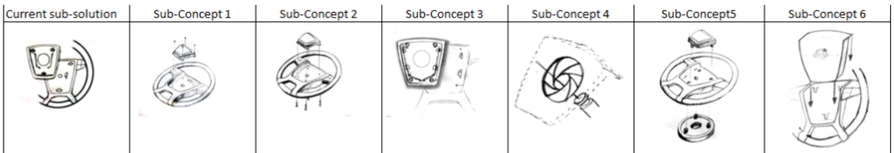
The current solution for the mounting of the DAB is described here. The current solution incorporates both flexible latches and flexible feet and these provide good guidance during the assembly of the steering wheel and DAB.

5.4 SUB-CONCEPT EVALUATION AND SELECTION

When the brainstorm is considered finished and a sufficient number of ideas have been generated it is time to select the best ones to go further into development. A common method for this is to use an evaluation matrix. Figure 9 presents the Pugh matrix for the Airbag mounting area, the matrices for all of the four areas can be found in Appendix F. In the evaluation matrix all concepts are rated against a reference concept or more commonly, the current product if it exists. The concepts are rated based on how well they fulfill certain criteria. These criteria could be based on for instance customer needs, stakeholder demands, design specifications and/or regulations. The reference is set to have zero (0) on each criteria and then all concepts are individually compared to the reference on each criteria, if it is considered better than the reference, it receives a plus (+) and if is worse it receives a minus (-). When all concepts have been rated the score is added up, a minus gives -1 point while a plus gives +1 point and a zero gives 0 points. A number of concepts with the highest total score are then taken further in the development process while those with lower points are eliminated.

There are a number of aspects to consider when performing this exercise, firstly how many concepts to take further. There are no definite rules for this, it all depends on the number of initial concepts and the problem they are to solve. Thus in this project the number of concepts that went to further development differ somewhat depending on the category.

Another important aspect is to have fairly equally important criteria. The reason for this is that the scoring is somewhat blind, it does not tell you what specific areas the concept was good at, and if there are criteria that are more important to fulfill than others the score can be misleading. It is therefore useful to investigate where certain concepts received many pluses or minuses and recognize their benefits or flaws. This misleading score can be prevented by doing a scoring matrix as a complement to the evaluation matrix. In the scoring matrix all the criteria are given a certain weight of importance, in this case 1-10, where a lower number refers to a lower importance. The scoring matrix also differs from the evaluation matrix in terms of how one compares the concepts to each other. There is no reference in a scoring matrix, instead each concept is rated individually on each criteria.



Airbag mounting	Current sub-solution	Sub-Concept 1	Sub-Concept 2	Sub-Concept 3	Sub-Concept 4	Sub-Concept5	Sub-Concept 6
Pugh Matrix	Current solution	The airbag is screwed from front	The airbag is screwed from back	Latches and springs	Aperture locking on steering col.	AB and CS mounted through SW	Slide the airbag from above
Short Assembly time	0	-	-	0	-	-	0
No additional tools needed	0	-	-	0	0	0	0
Simplifies assembly operations	0	-	-	0	0	-	-
few separate operations needed	0	-	-	0	-	0	0
Resistance to human errors (memory)	0	+	+	0	0	0	0
Good Feedback to assembly personnel	0	+	+	0	0	0	0
minimizes risks for gap and/or flush	0	+	+	0	0	+	+
Able to verify mounting	0	+	+	0	0	0	0
Low Number of parts	0	-	0	0	-	0	-
Manufacturable	0	0	0	+	-	-	-
Lower Cost	0	0	0	+	-	-	-
Good guidance for airbag	0	+	+	0	0	0	+
Provides possibility for more ergonomic ass.	0	+	+	0	-	+	+
Easier to assemble than disassemble	0	0	+	+	0	+	0
sum +	0	6	7	3	0	3	3
sum -	0	5	4	0	6	4	4
sum 0	14	3	3	11	5	7	7
Total score	0	1	3	3	-6	-1	-1
Rank	**3**	**2**	**1**	**1**	**5**	**4**	**4**

Figure 9: Evaluation of the airbag mounting using a Pugh matrix. The first four shaded columns represent the winners and the last three represent the eliminated sub-concepts.

5.5 SYNTHESIZING SYSTEM-CONCEPTS - THE MORPHOLOGICAL MATRIX

When the individual sub-concepts have been narrowed down to a number of promising ones it is time to combine these into the complete product structure or system-concepts. The use of morphological matrices is ideal for this purpose. It provides an easy overview of how variants of parts can be combined with each other. The morphological matrix constructed during this project is illustrated in Figure 10. The first column presents the four different problem areas for which the individual sub-concepts were generated. Each row incorporates the winning sub-concepts from the sub-concept selection stage for their respective area. The method for using the morphological matrix is very pedagogic and straight forward. The purpose is to generate combinations of the different sub-concepts which will create new system-concepts for the system architecture. In practice this is done by combining *one* sub-concept from each row into a new system-concept consisting of, in this case, four sub-concepts. This can be done by carefully selecting sub-concepts one by one for combination or it can be done randomly.

In this project, both methods were used, one sub-concept from each area was randomly selected and then put together, this process was then repeated a number of times. After the random selection, a reflection was made about the randomly selected system-concept in order to identify new combinations that could be better. Some combinations were not realistic or necessary and these were scrapped. For instance sub-concept 2 of *Airbag mounting*, "Airbag screwed from the front" combined with sub-concept 3 of *Airbag to SWM connection*, "Flexible Connector", is irrelevant since if the airbag is screwed to the steering wheel there is no need for the flexible connector. Sixteen system-concepts were combined by random selection and then six additional system-concepts were selected by careful consideration. This resulted in a list with 22 individual system-concepts that were to be evaluated further. The list can be viewed in Appendix G.

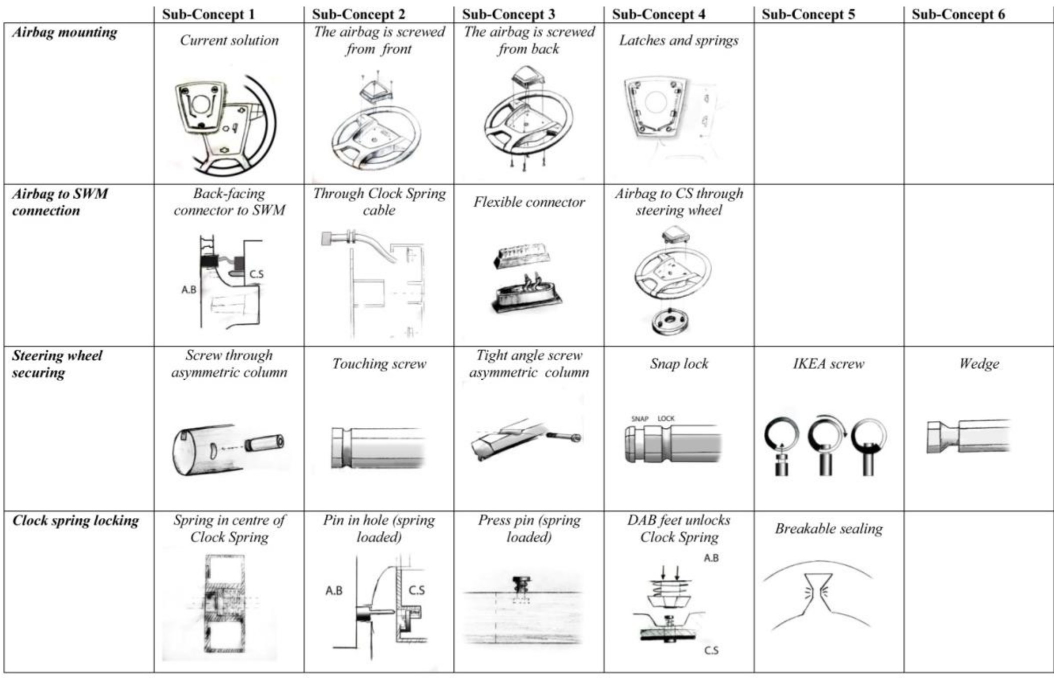


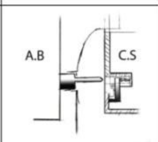
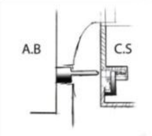
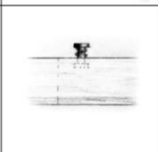
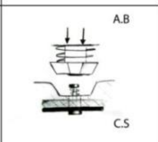
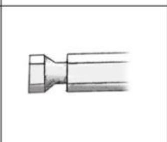
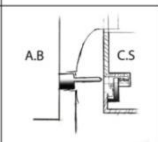
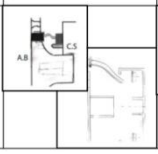
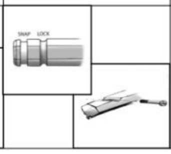
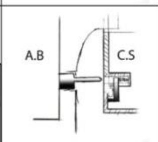
Figure 10: Morphological matrix. The issues identified during the function analysis are presented in the first column to the left. Each row then contains the winning sub-concepts from the evaluation matrices. In order to synthesize a system-concept one must choose one sub-concept from each row and connect them. If it is possible, two sub-concepts can also be combined into one.

6 EVALUATION OF PROMISING SYSTEM-CONCEPTS

The result of the morphological matrices was a vast number of combinations which in turn can be viewed as completely new concepts, so called system-concepts. These had to be evaluated in order to find the best ones suitable for further development in the detailed development stage where more detailed system-concept presentations would be made with CAD models. An evaluation matrix similar to the one used in the sub-concept selection phase was implemented, the difference however was that it was far more extensive since it featured all the criteria used in each previous evaluation matrix, at the same time.

The concept selection process for the system-concepts resulted in both a Pugh evaluation matrix and a Kesselring scoring matrix. The Pugh matrix eliminated half of the system-concepts, leaving eleven system-concepts to go into the Kesselring matrix. The Kesselring matrix in turn eliminated five of these eleven system-concepts and left six system-concepts as winners, the matrices can be viewed in Appendix H. The six winning system-concepts for the complete system are presented in Table 7 below. All of the criteria used in the individual sub-concept evaluations were used together in the system-concept evaluation matrices in order to ensure that the winning system-concepts met most of the stated criteria, thus fulfilling most of the needs stated during the pre-study.

Table 7: Winning system-concepts from morphological matrix.

	Airbag mounting	Airbag to SWM connection	Steering wheel securing	Clock spring locking	RANK
System-Concept 22					1
System-Concept 20					2
System-Concept 18					3
System-Concept 14					4
System-Concept 17					5
System-Concept 21					6

Together with the stakeholder it was decided that four of the six winning system-concepts in Table 7 would go further into detailed development. The chosen system-concepts were number 14, 20, 21 and a variant of system-concept 14. The variant of system-concept 14 will from this point be named “system-concept 1421”. System-concept 1421 was chosen since it was of great interest to the stakeholders, it incorporated features that seemed feasible and that were innovative in nature. System-concept 1421 incorporated the airbag mounting and SWM connection of system-concept 14 but the steering wheel securing and clockspring locking of system-concept 21. System-concept 1421 was investigated by conducting the same evaluation of it as the other system-concepts in the Pugh and Kesselring matrices and the result was that it received 4th place in the rankings and thus was eligible for further development.

The motivation for choosing these system-concepts was mainly their innovative nature. Especially interesting was the *Airbag to SWM connection* in system-concept 14, the steering wheel securing in system-concept 21 and the clockspring locking in system-concept 20 and 21.

As seen in Table 7 the last system-concept, number 21, includes a combination of two sub-concepts for the “securing of the steering wheel to the steering column” issue. This combination was also used in system-concept 1421. It is a combination of the “Asymmetric steering pivot with angled screw” and the “Snap-Lock”. Figure 11 illustrates how this combination would look in practice.

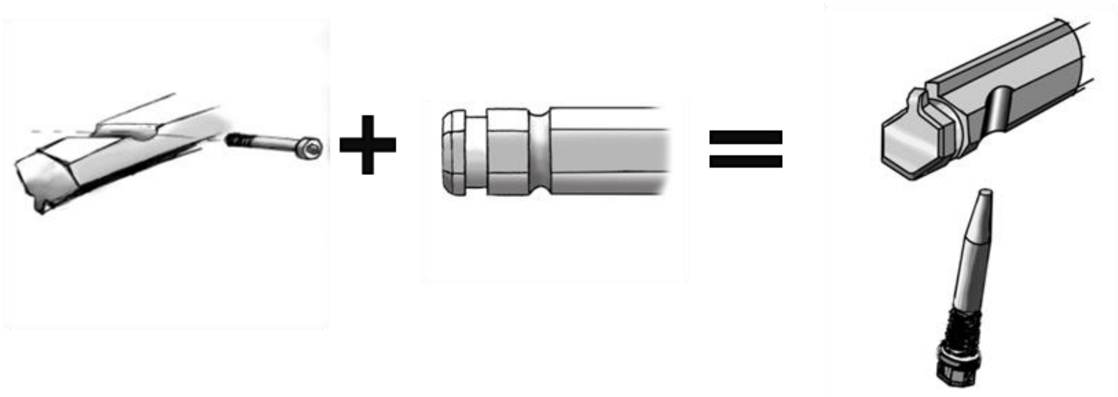


Figure 11: Illustration of the result from the combination of "Snap-Lock" with "Asymmetric steering column pivot with angled screw".

7 DETAILED DEVELOPMENT OF THE WINNING SYSTEM-CONCEPTS

After the system-concept evaluation was made regarding which ones of the system-concepts to develop further it was time to refine the system-concepts by doing CAD models. CAD models are used to better illustrate how the system-concepts could look and function in real life. CAD models also have the advantage that they can easily be made into physical models by utilizing rapid prototyping methods. Thus, in this chapter the four winning system-concepts will be presented by showing, both CAD pictures and the rapid prototypes that were made. The prototypes and refined system-concepts are then to be evaluated in screening 3. The descriptions of the system-concepts in this chapter refer to the way they are assembled as the main focus of the project was to improve the assembly operations.

7.1 DESCRIPTION OF SYSTEM-CONCEPT 20

The initial idea of system-concept 20 was to basically use the current solution and modify and adapt it to a one-piece assembly. The basic look of the assembly would not be altered so the driver would not notice any difference, however the inside of the assembly would need some modifications. Figure 12 illustrates the different sub-concepts included in system-concept 20.

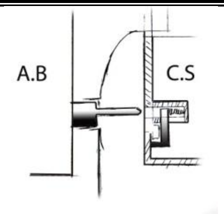
Current solution of the airbag module	Flexible connector	Asymmetric steering pivot with angled screw	Pin in hole from steering wheel to release clockspring
			

Figure 12: System-concept 20 and its different sub-concepts.

The assembly procedure for system-concept 20 is very different compared to the one used for the current solution. In order to have a one-piece assembly all features on the steering wheel are assembled on a pre-assembly station, outside the production line. The main difference from the current solution is that the airbag module is mounted onto the steering wheel before it is attached to the steering column pivot. The attachment features of the DAB [2] to the steering wheel is however the same as the current solution. Instead of using cables from the airbag, a fixed connector [3] is placed on the DAB [2]. This fixed connector [2] is later connected to the flexible connector [4] residing in the clockspring [1], see Figure 13.

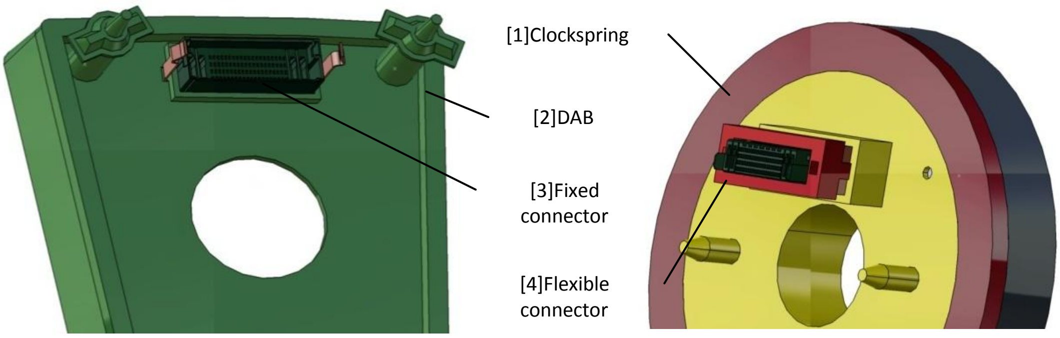


Figure 13: Detailed development of system-concept 20, the DAB and clockspring with their respective connectors to transfer the electrical signals.

The complete steering wheel with DAB and its other features attached to it is mounted onto the asymmetric steering column pivot [5]. The asymmetric profile of the steering column pivot ensures that the steering wheel only can be mounted in one specific orientation and is always aligned with the front wheels of the car, see Figure 14. To secure the steering wheel onto the steering column an angled screw [6] is entered in a slot on the side of the steering column pivot [5]. The screw [6] is first attached in an insert body [8] inside the steering wheel on the pre-assembly station and through a hole in the bottom on the steering wheel the screw [6] is accessible for tightening, see Figure 16.

When the screw is tightened, a force is provided. This force can be dived into two components, one radial and one axial to the steering column pivot. The axial force is used to press the steering wheel on the cone shape [7] on the steering column pivot and prevent play in the attachment point, see Figure 15.

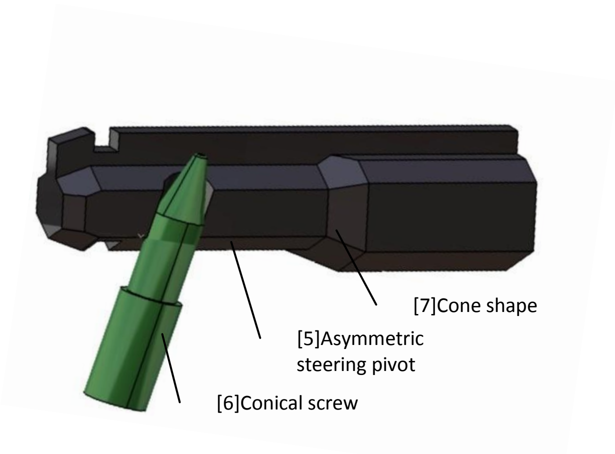


Figure 14: System-concept 20, CAD representation of the asymmetric steering column pivot with angled screw.

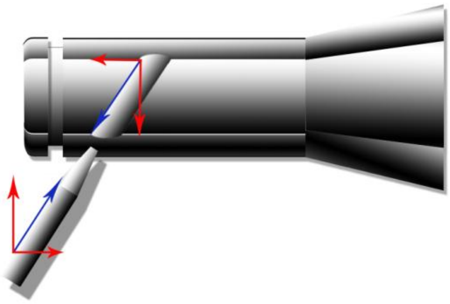


Figure 15: Illustration of how the forces generated by the insertion of the screw are distributed.

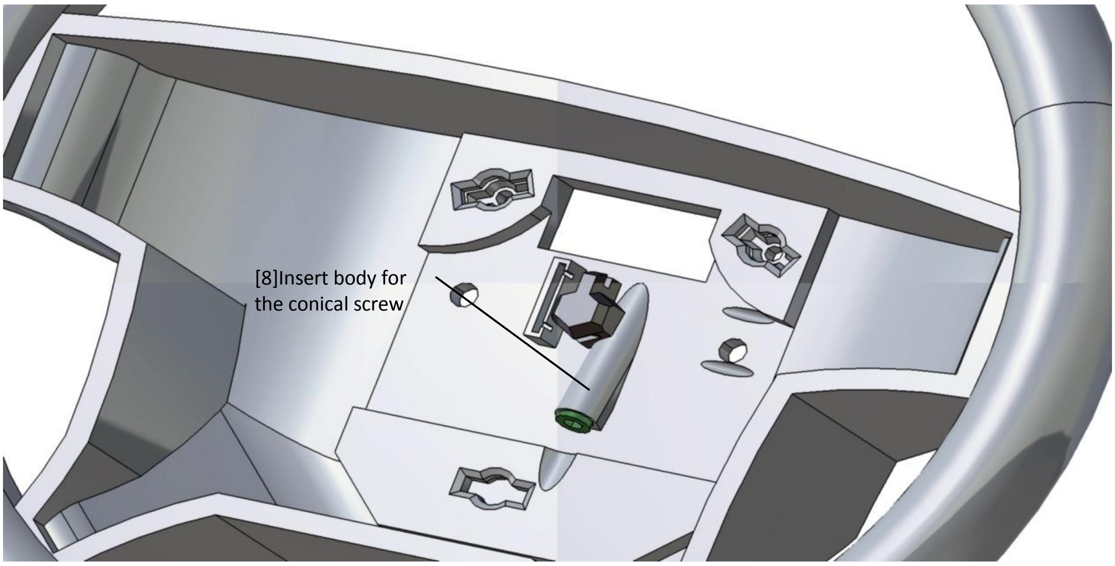


Figure 16: System-concept 20, the inside of the steering wheel illustrated as a CAD model. The conical screw resides in an insert body [8] molded into the frame material of the steering wheel. The hole which the steering column pivot is to go through has the same asymmetric shape as the screw.

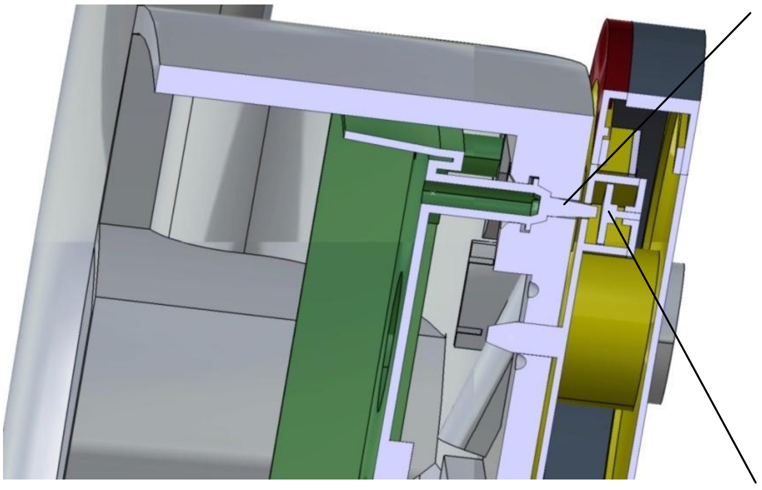


Figure 17: System-concept 20, intersection illustration of the inside of the steering wheel assembly with the DAB mounted and clockspring unlocked by the DAB feet pin.

The clockspring locking and unlocking function in system-concept 20 is in the form of a pin which is situated on the DAB feet [9], Figure 17. When the steering wheel is mounted a pin from the DAB feet is pushing a releasing mechanism inside the clockspring [10]. This releasing mechanism is submerged into the clockspring, which prevents any unintended releasing.

ADVANTAGES

The possibility to use the current solution for the airbag module saves development cost and time since it only needs to be modified to fit with the rest of the system-concept features. The cover plate in the middle of the airbag module, which is used as a protection of the vibration damping device, is not longer necessary. The fixated connector makes it possible to have control over the cables and all oversized cable slack is not longer needed. This in turn means that the cable from the clockspring can be reduced as well since it is replaced by the flexible connector.

In system-concept 20 many steps in the assembly can be moved from the line to a pre-assembly station. On a pre-assembly station the personal would not have the same time pressure as they have on the line and at the same time they would have a better overview of the assembly. The personnel can check the steering wheel from different angles to investigate that all part are correctly assembled, which is not the case when it is assembled inside the car. Better control and guidance of the cables also enhances the reliability of the assembly. This increases control and overview possibilities of the assembly which leads to less quality issues and less intervention needed later on in the assembly process.

DISADVANTAGES

The system-concept 20 has some uncertainties though. The angled screw needs to provide enough axial force against the steering column so that no play can occur in the steering wheel. The new connectors need to undergo some tests, such as vibration tests, climate tests and insertion tests, to verify that the system fulfills its function and has the robustness needed.

With the solution of using an angled screw there is no possibility for the assembly personnel to know that the steering wheel is in the right position and thus that the screw can be tighten. This leads to unnecessary uncertainties and can cause damage to the steering wheel or the screw and the complete assembly of that car might need to be stopped at the assembly line to fix it, which adds unnecessary assembly time.

7.2 DESCRIPTION OF SYSTEM-CONCEPT 21

System-concept 21 is a completely new concept that differs very much from the current solution. Figure 18 illustrates the system-concept with its different sub-concepts.

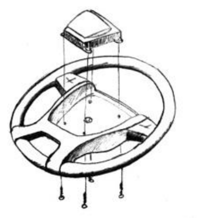
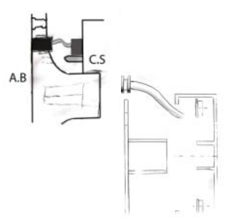
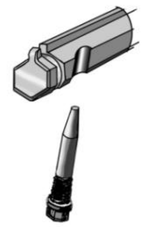
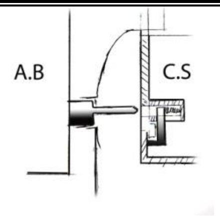
Screw Airbag from back	Combination of, Back facing connector to SWM and Straight through cable from clockspring	Combination of, Snap-Lock and Asymmetric steering pivot with angled screw.	Pin in hole from steering wheel to release clockspring
			

Figure 18: System-concept 21 with its different sub-concepts.

In the same manner as in system-concept 20, the complete assembly of the steering wheel is made on a pre-assembly station. One difference is that the airbag module [3] is screwed onto the steering wheel from the back with two screws [4], see Figure 19. Since the airbag module is screwed it has no flexibility, which means that the floating horn function needs to be solved in another way. This can be solved with a floating cover [1] on top of the airbag module which is attached with latches and springs to the steering wheel deco plastic [2]. The appearance and feeling to the driver is however the same as the current solution.

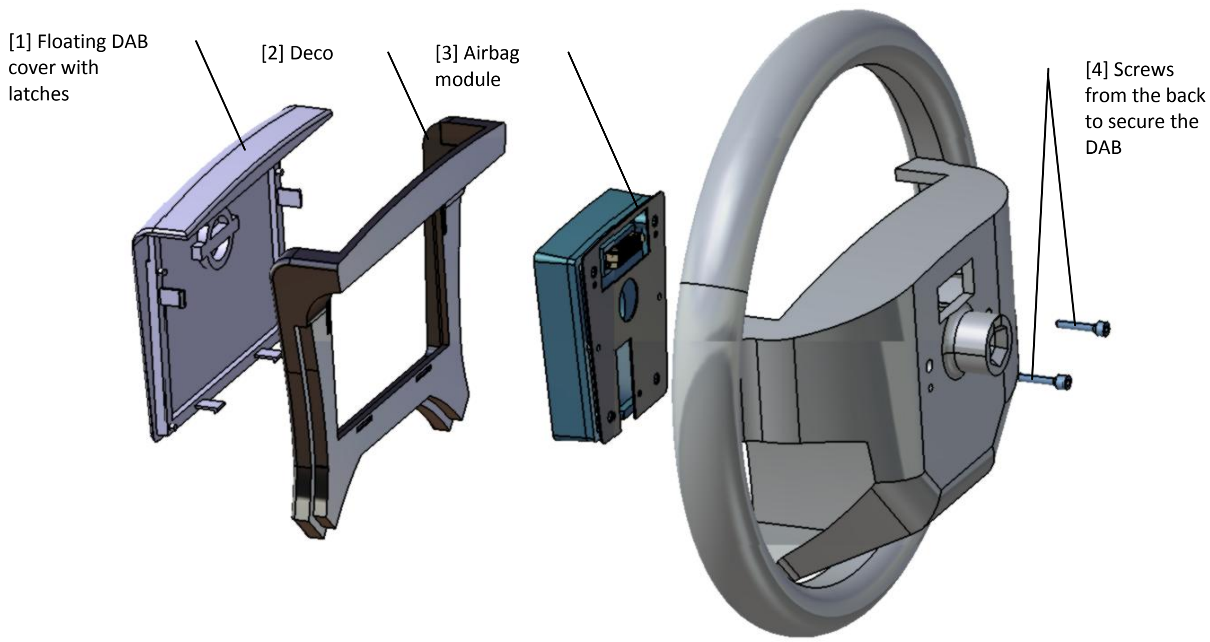


Figure 19: System-concept 21, CAD illustration of the assembly of the steering wheel, DAB, deco and DAB-Cover.

When the assembly operations on the pre-assembly station are done it is time to attach the steering wheel to the steering column pivot. However, before the steering wheel is pushed into its place, the connection between the DAB connector and clockspring has to be done. The airbag module has a back facing connector, see Figure 20-21 [5], that is accessible through a hole on the backside of the steering wheel. From the clockspring, a cable with a predefined cable slack is connected to the back facing connector. In order to reduce the amount of connectors in the system, the flat cable inside the clockspring is run straight through the outer casing and is directly connected to the back facing connector as previously described.

The steering wheel is attached onto the asymmetric steering column pivot [7] similar to the one used in system-concept 20. However, an additional feature has been added to this system-concept, the Snap-Lock sub-concept. A clip [6] has been integrated in the steering wheel and a groove has been added to the steering column pivot. When the steering wheel is mounted to the steering column pivot the clip “snaps” in to the groove and makes a clicking sound. This sound works as feedback which informs the assembly personnel that the steering wheel is in the right place and that the screw [8] is in its proper position and ready to be screwed in.

When it comes to the unlocking of the clockspring, an automated function is implemented in this system-concept. When the steering wheel is mounted, a pin from the steering wheel pushes on a releasing mechanism inside the clockspring. This releasing mechanism is submerged into the clockspring, to prevent unintended releasing, see Chapter 7.1, Figure 17.

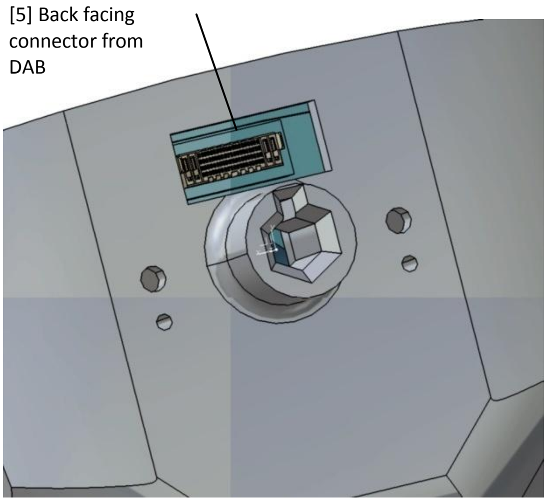


Figure 20: System-concept 21, Backside of the steering wheel with back facing connector from DAB.

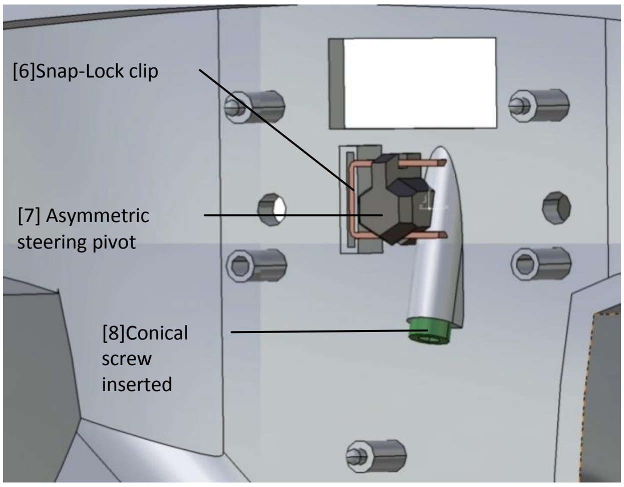


Figure 21: System-concept 21, Inside of the steering wheel when attached to the steering column pivot with conical screw and "Snap-Lock" clip.

Advantages

Attaching the airbag module with screws provides a measurable verification of the assembly. A torque and a specific amount of revolutions can verify that the screws have been firmly attached. This provides a good feedback to the assembly personnel that the assembly has been done correctly. Another advantage when using screws is that it increases the quality of the assembly. The current solution, which uses latches and feet that are inserted in the foam of the steering wheel, is not as accurate as if it would be screwed down. The foam is flexible and the DAB feet are hard and have a lot of sharp edges, worst case scenario is that the DAB feet cut into the foam instead of being guided by it, this can in turn cause the DAB to be incorrectly mounted. The driver will see this incorrect assembly since gaps in the product can be offset and this can give the driver a negative view on the quality of the car.

The feedback feature provided by the Snap-Lock clip lets the personnel know that the steering wheel is in the right position and that the screw can be tightened. This feature ensures that the screw cannot be tightened if the steering wheel is mounted incorrectly. The clip also increases the anti-theft protection since it makes the steering wheel more difficult to dismount from the car.

Reducing the number of connector transitions can reduce the risk of disturbances in the SRS signal. With no steps between the inner cable of the clockspring and the cable connecting to the airbag module it is possible to reduce one connector transition and have a more stable input signal to the inflator.

Disadvantages

Compared to system-concept 20, more steps are needed both on the pre-assembly station and the assembly line. The mounting of the airbag module with screws requires some sort of tool and the floating cover above the airbag module must be mounted. These two extra tasks in the assembly process adds both total assembly time and the number of steps made in the total assembly. The manual connection of the connectors between DAB and clockspring adds time and steps as well. Furthermore, this connection needs to be done inside the car, which makes it even more difficult than if it had been done on a pre-assembly station.

7.3 Description of system-concept 14

System-concept 14 is very similar to system-concept 20 with the only difference being how it unlocks the clockspring. The system-concept together with its sub-concepts is shown in Figure 22.

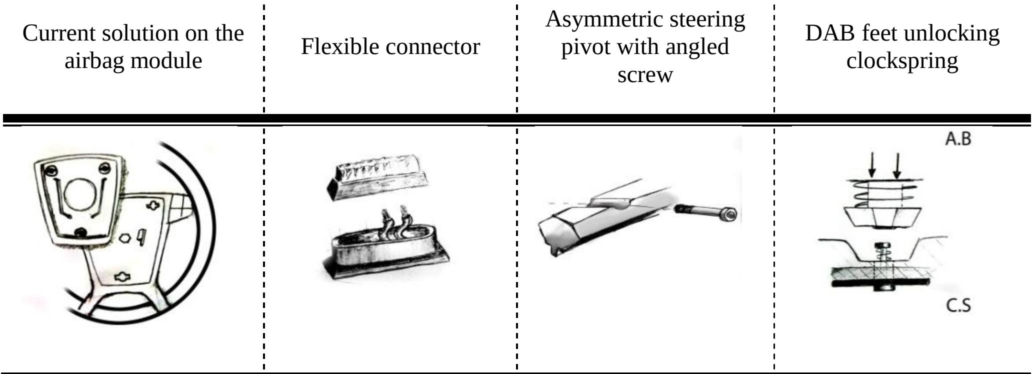


Figure 22: System-concept 14 with its different sub-concepts.

System-concept 14 uses the same sub-concept solutions for *Airbag mounting*, *SWM connection* and *Steering wheel securing* as system-concept 20 which has been described on the preceding pages. The assembly procedure is also exactly the same. Thus the focus when describing system-concept 14 will only be on the clockspring unlocking sub-concept, “DAB feet unlocking clockspring”.

The clockspring locking of system-concept 14 is an automatic unlocking solution. At the same time as the steering wheel is mounted on the steering column pivot the feet’s on the airbag module pushes on a button located beneath each foot. These buttons are connected to the clockspring and releases it if all three of the DAB feet are pressed in correctly and makes it possible rotate the steering wheel. This function provides a feedback to the personal that the airbag module is mounted correctly if it is possible to turn the steering wheel. If the module is not mounted correctly, the steering wheel cannot be rotated and the assembly of the airbag module has to be redone.

Advantages

Because of the similarity to system-concept 20, system-concept 14 shares many of its advantages. However, the sub-concept for releasing the clockspring in system-concept 14 deals with the issue of feedback to the assembly personnel regarding the airbag module mounting. If the airbag module is mounted incorrectly the horn might not function properly and the connection to the SRS signal might be disturbed. The airbag module must therefore be placed correctly in order to connect the DAB to the flexible connector. This scenario can be prevented with the feedback from the airbag module feet pushing on the release buttons.

Disadvantages

System- concept 14 has no unique disadvantages, instead it shares the same disadvantages as system-concept 20, which have been discussed on the preceding pages.

7.4 DESCRIPTION OF SYSTEM-CONCEPT 1421

The System-concept 1421 is, as said before, a combination of system-concept 14 and 21. It incorporates the airbag mounting and SWM connection from system-concept 14 and the steering wheel securing and clockspring unlocking from system-concept 21. An overview of the included sub-concepts can be seen in Figure 23.

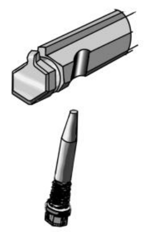
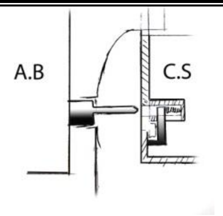
Current solution on the airbag module	Flexible connector	Combination of, Snap-Lock and Asymmetric steering pivot with angled screw.	Pin in hole from steering wheel release clockspring
			

Figure 23: System-concept 1421 and its different sub-concepts.

The assembly procedure for system-concept1421 is the same as for system-concept 14. The main differences between them are the Snap-Lock feature and the releasing of the clockspring. The Snap-Lock gives an anti-theft protection and it is designed in such a way that it can only be released when the steering wheel is turned 90 degrees and the steering wheel is unlocked. With the steering wheel in this position, the service personnel can reach two holes on the backside of the wheel [1], through the holes they can reach the clip and release it, see Figure 24. Just as in system-concept 21, the releasing mechanism for the clockspring is a pin from the steering wheel that pushes on a button in the clockspring.

ADVANTAGES

The advantage of system-concept1421 is the combination of fulfilling many desired functions while at the same time being innovative. The flexing connector combined with the Snap-Lock and asymmetric steering column pivot reduces steps in the assembly and at the same time secures that the assembly is made properly. Using the current solution for the airbag mounting saves some development cost.

DISADVANTAGES

System-concept 1421 requires a lot of blind mating and automated connection, which can be a problem from an assembly perspective since you do not know for sure that the connection is made, thus the solution needs to be fail-safe. If the connection is not done right or if something is assembled incorrectly it might lead to delays in the production and this is not desirable.

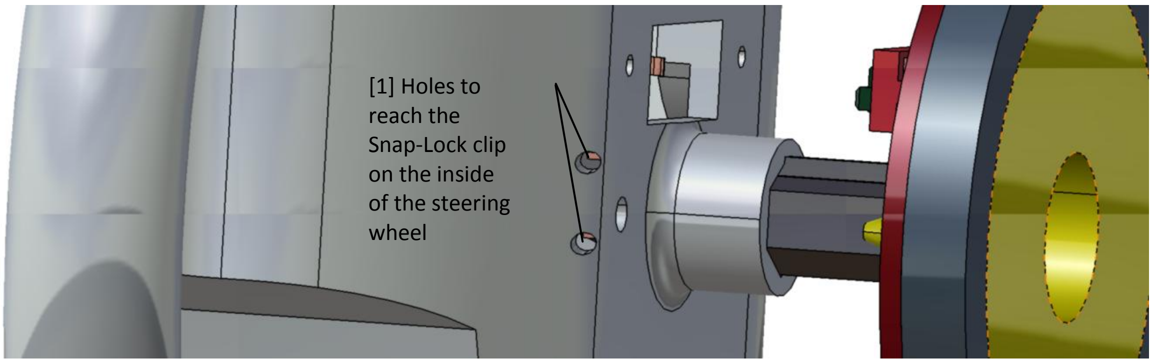


Figure 24: System-concept 1421, the back of the steering wheel with the holes to reach the clips.

7.5 CALCULATIONS OF AXIAL FORCE ON THE STEERING COLUMN

Calculations of the axial force (F) of the steering column pivot were made to determine how much force (A) on the screw that is required to gain the same axial force (F) as the current solution provides in the x axis direction. As can be seen in Figure 25 the screw is tightened with a tool, and thereby provides a force (A), in an angle of α to the y axis. Because of the conical shape of the screw all forces provided by the screw will inflict on the edge of the groove in the steering column pivot. With this in mind the force (A) can be divided into two components. One will follow the angle of the cone shape, angle β, of the screw (B) and the other (C), perpendicular to force (B). Force (B) and (C) can in turn also be divided into their respective component forces, see Figure 26 and Figure 27. The size of force (A) and force (B) can be found in equation 1 and 2. Known variables in these equations are force (A), angle α and β and the friction coefficient μ.

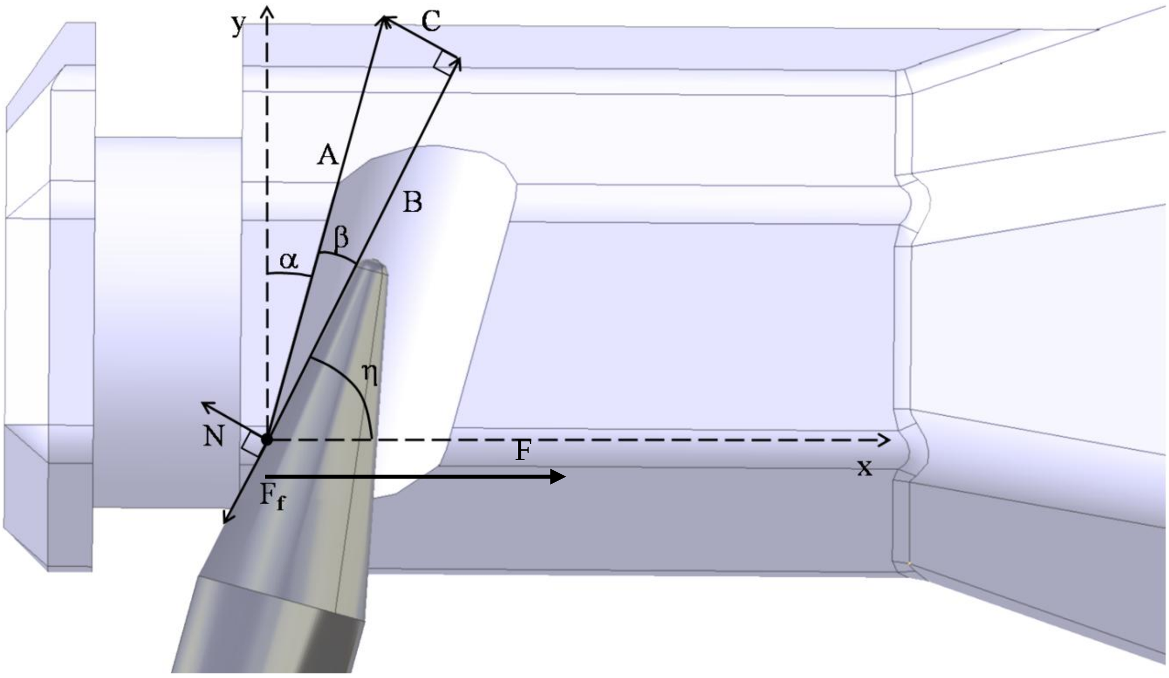


Figure 25: Illustration of the force distribution for the insertion of the conical screw.

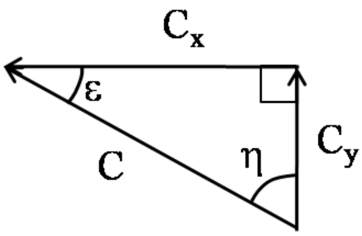


Figure 26: Illustration of the force component distribution of force (C) in Figure 25.

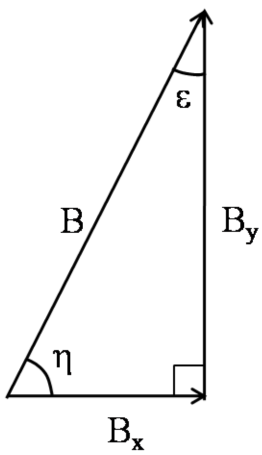


Figure 27: Illustration of the force component distribution of force (B) in Figure 25.

$$B = A\cos(\beta) \qquad (1)$$

$$C = A\sin(\beta) \qquad (2)$$

Due to the angle of the cone on the screw a friction force (F_f) has to be taken into consideration. F_f can be calculated by equation 3.

$$F_f = C \cdot \mu = \mu \cdot A \cdot \sin(\beta) \qquad (3)$$

As the friction works against force (B) the resulting force (B_{res}) can be calculated as equation 4.

$$B_{res} = B - F_f = A \cdot \cos(\beta) - \mu A \sin(\beta) \qquad (4)$$

The force (C) can also be divided into two component forces (C_y and C_x), as described in Figure 26 C_x is one of the forces contributing to the axial force (F). Calculation of C_x can be found in equation 5.

$$C_x = C\cos(\varepsilon) \qquad (5)$$

ε can be calculated as equation 6.

$$\varepsilon = \alpha + \beta \qquad (6)$$

Combination of equation 5, 2 and 6 gives C_x.

$$C_x = A\sin(\beta) \cdot \cos(\alpha + \beta) \qquad (7)$$

The force (B) can be divided into two component forces (B_y and B_x). The interesting component for the axial force (F) is B_x.

$$B_x = B_{res} \cos(\eta) \qquad (8)$$

η can be calculated as:

$$\eta = 90 - \alpha - \beta \qquad (9)$$

Combination of equation 8, 4 and 9 gives B_x.

$$B_x = (A\cos(\beta) - \mu A \sin(\beta)) \cdot \cos(90 - \alpha - \beta) \qquad (10)$$

The resulting axial force (F) from the screw force (A) can be calculated as.

$$F = B_x - C_x \qquad (11)$$

$$F = (A\cos(\beta) - \mu A \sin(\beta)) \cdot \cos(90 - \alpha - \beta) - A\sin(\beta) \cdot \cos(\alpha + \beta) \qquad (12)$$

To calculate the provided force from the screw (A) and to gain an axial force (F) equal to current solution equation 13 may be used.

$$A = \frac{F}{(\cos(\beta) - \mu \sin(\beta)) \cdot \cos(90 - \alpha - \beta) - \sin(\beta) \cdot \cos(\alpha + \beta)} \qquad (13)$$

To calculate the axial force (F) provided by the angled screw force (A), equation 12 can be used. If it is desired to calculate the angled screw force (A) for a certain desired axial force (F), equation 13 can be used.

7.6 CALCULATIONS OF DEFORMATION OF STEERING WHEEL INTERFACE

To gain appropriate attachment between the steering wheel and the steering column pivot, the conical shape in the steering wheel deforms during tightening of the securing screw. This method enhances the screw joint and the risk of play reduces considerably. The implementation of the sub-concept with an angled screw posed the question if it provided the necessary deformation to secure the steering wheel properly, thus some calculations were made to investigate this. Known variables in these calculations are A, E, L and ΔL.

The current solution deforms the steering wheel ΔL mm when the securing screw is tightened. Verifying the axial force (F) needed to gain this deformation two approximations can be used. The deformation zone has a conical shape but to simplify the calculation, an assumption is made. If the deformation area of the interface is perpendicular instead of conical, the axial force needed to deform the steering wheel interface is greater compared to a conical shape. With a perpendicular face more material has to be deformed, which means that more force is needed. With these estimations it is possible to determine a deformation force greater than the actual force needed. The differences between the estimation and actual interface can be seen in Figure 28. The main body of the estimated steering wheel interface has a cylindrical shaped design.

The second approximation is to only use the part of the interface that has this design. This will make the interface shorter than the actual interface and the result of this estimation gives a higher force than the actual required. Thus, if the calculations prove the angled screw to provide enough force to deform the assumed interface, it most certainly will be enough to deform the actual interface.

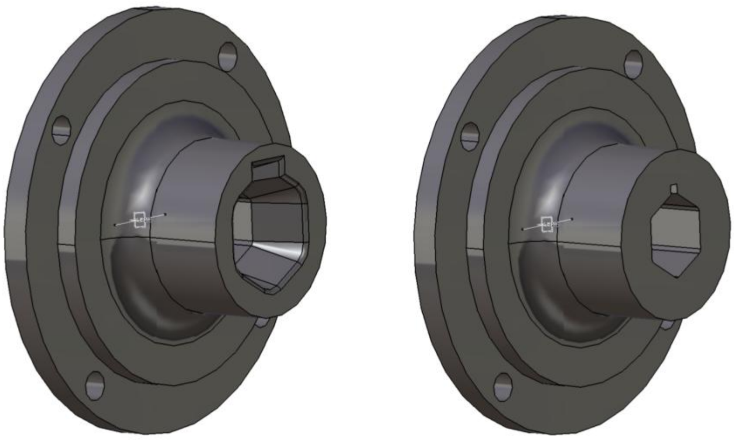


Figure 28: Steering wheel interface. The picture to the left illustrates the actual interface area with a conical shape and the picture to the right illustrates the estimated interface area.

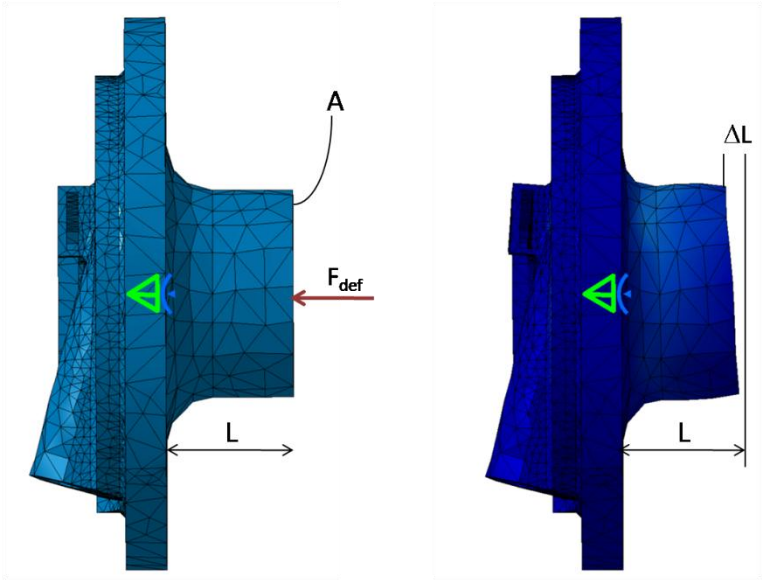


Figure 29: The steering wheel interface seen in its undeformed state to the left and in a deformed state to the right. As can be seen the length L has decreased with ΔL and deformed the interface where the steering column pivot is inserted, this minimizes play in the assembly.

With the two approximations mentioned above it is possible to calculate a force (F_{def}) higher than the actual needed force. Combining this with the information from Chapter 7.5 makes it possible to determine if the angled screw provides enough axial force. The following three well know equations for calculation of deformations is used.

$$\sigma = \frac{F_{def}}{A} \tag{14}$$

$$\varepsilon = \frac{\sigma}{E} \tag{15}$$

$$\Delta L = \varepsilon \cdot L \tag{16}$$

Where F_{def} is the axial force on the interface area, σ is the stress, ε is the strain, A the area of the interface, E is Young's modulus, L the length of the interface and ΔL is the total length change. Figure 29 presents the deformation of the steering wheel interface, the figure has been obtained from a Finite Element Analysis software where the deformation force $F_{def,}$ calculated below, was placed on the area A to see how the interface reacted.

Combining equation 14, 15 and 16 the force needed to deform the interface ΔL can be calculated as:

$$F_{def} = \frac{\Delta L \cdot E \cdot A}{L} \tag{17}$$

7.7 Result of calculations

With an overestimation of the deformation force (F_{def}), it could be said that the axial force (F), gained from the angled screw force (A), in Chapter 7.5, is greater than the deformation force (F_{def}) needed to deform the interface ΔL. A deformation will be made but it cannot be established if the axial force (F) from the angled screw is enough to resist plays in the interface gained from vibrations and loads from driving the car. This must be confirmed by testing.

7.8 Detailed development prototype

Some of the sub-concepts incorporated functions that needed to be verified in practice, therefore prototypes were made. After discussing the matter with the stakeholders it was decided that prototypes of the flexing connector and the asymmetric steering column with Snap-Lock and angled screw were of most interest since they had the most complex functionalities.

7.8.1 Prototype of flexible connector

Developing connectors for the car industry requires a lot of testing and evaluation. In order to reduce the cost and time which such tests generate it was desired to find connectors that already had been tested thoroughly and then perhaps modify them. After some research it was found that the connector that best met the requirements was a blind mating connector from Samtec Inc. The Samtec Inc. connector incorporated some features that were of good use to the application of the flexible connector. Such features were, chamfered edges to aid the positioning of the connectors and guide them towards each other when blind mated. Other useful features were a set of locking hooks which resulted in that it required a greater unmating force than the one needed to mate them together. However the Samtec Inc. connector was primarily intended for electronic appliances. It was too small and was not intended for automotive industry usage, thus it was not possible to simply modify the connector as such, so instead a new connector had to be designed, utilizing the same features.

As can be seen in Figure 30 the proposed flexible connector has chamfered edges, which reduces the influences of angle and manufacturing tolerances, i.e if the alignment between the airbag module and the clockspring is not perfect these edges guide the connectors towards each other. This connector can be connected if the angle between the two connectors is less than 2 degrees. The connecting pins of the connectors are located on the outer and inner walls of the connecting surfaces. That location contributes to the possibility to connect one side of the connector and then push the other side into the connector. This is not possible if pins in holes had been used, as in traditional connectors. Using such pins could result in bended or damaged pins if the connectors are assembled with an angle.

Four locking hooks, two in each connector, secure the connectors when they are attached to each other. The locking hooks are constructed in a similar way to the Samtec Inc. connector resulting in a larger unmating force needed compared to the mating force. This makes it possible to mate and separate the connectors without using tools and only push and pulling force is needed. This is important since there will be no possibility to reach the connector in the one-piece assembly when the airbag module is in the way.

Since the Samtec Inc. connector is not designed for this kind of application some features are missing. The connector has for instance no flexing possibility and short circuit connectors are missing. Without these features the connectors cannot be used as a flexing connector for an airbag module and clockspring application.

With the connector from Samtech Inc. as inspiration two new connectors were made. The desired features were implemented into a complete connector. As can be seen in Figure 30, the prototype for the flexing connector has chamfered edges, connecting pins on the outside walls and locking hooks to secure the mating. As demanded for these types of connector short circuit connectors have also been integrated.

Under one of the connectors, two springs are integrated to provide the flexibility needed. This feature makes it possible to have two blind mating connectors and provide a flexible airbag module. The connector is attached with two latches to a plate and the springs presses the flexible connector upwards and keeps the connector in its top position to ensure that the flexible connector is in its right position when the two connector parts are mated.

The prototype was modeled with a Free Form Fabrication (FFF) method which is common when simple prototypes are desired for initial tests, Figure 31 shows a photograph of the FFF produced prototype. Important tests with this prototype were; a fitting test, angle tolerances and flexibility tests. The evaluation of these tests can be found in Chapter 8.

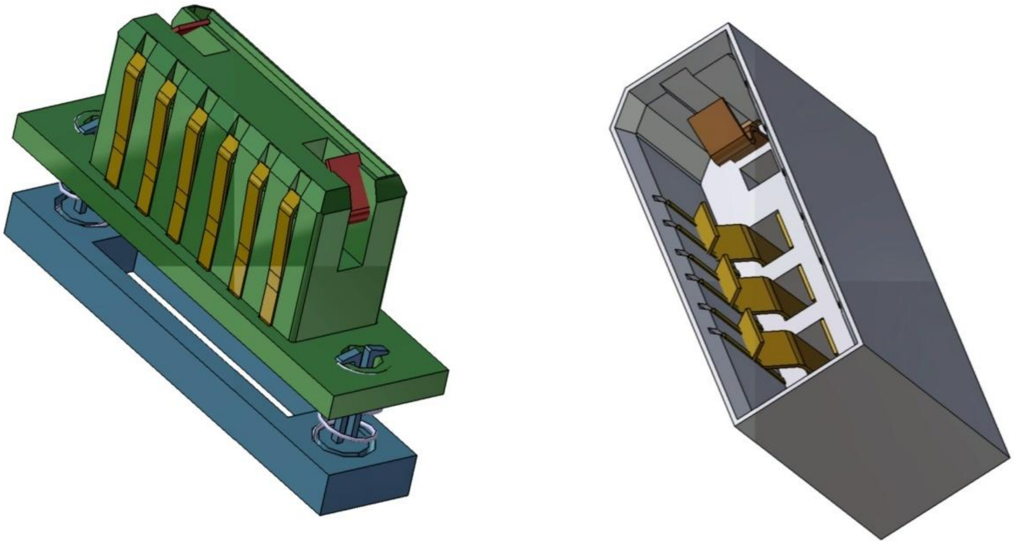


Figure 30: The flexible connector designed for this project. The connector assembly is made up of three major parts; the holder for the springs which provides the flexibility, the connector attached to the springs and the connector which is to be mated with the flexible connector. The two connectors feature locking hooks and chamfered edges to aid mating. The connector which is not flexible also incorporates short circuit connectors which are needed in airbag applications due to safety regulations.

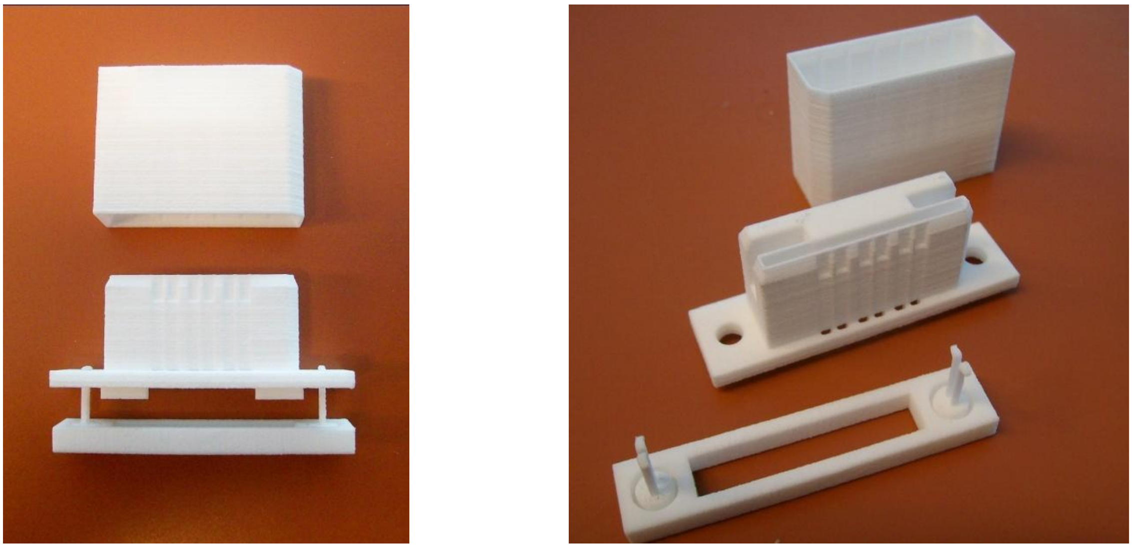


Figure 31: Photograph of the FFF prototype made of the flexible connector. Terminals, locking hooks and short circuit connectors were not included in this prototype, springs were however added later (not shown in this picture) to test the flexibility.

7.8.2 PROTOTYPE OF ASYMMETRIC STEERING COLUMN PIVOT WITH ANGLED SCREW AND SNAP-LOCK

A prototype was first designed using CAD software, the model can be seen in Figure 32. The purpose of the prototype was to test if the angled screw could provide enough force to secure and fix the steering wheel to the steering column. To minimize the cost of the prototype, an adapter pivot, which can be screwed to the current steering column pivot was designed. As can be seen in Figure 32 the adapter is asymmetric and has the appropriate groove for the screw to fit in. A groove around the end of the adapter pivot was implemented to work as the stop for the clip.

The prototype was manufactured in both metal and FFF material, it can be seen in Figure 33. The metal parts were the adapter pivot, the screw and a threaded insert which the screw was to be inserted in. The plate representing the interface of the steering wheel was however made in FFF material due to its complicated shape. It was not necessary to produce a metal interface of the steering wheel at this stage since the purpose was to simply investigate if the screw could be inserted properly and if it secured the steering wheel properly. However to investigate how the steering wheel interface would deform, a more realistic prototype in metal should be manufactured.

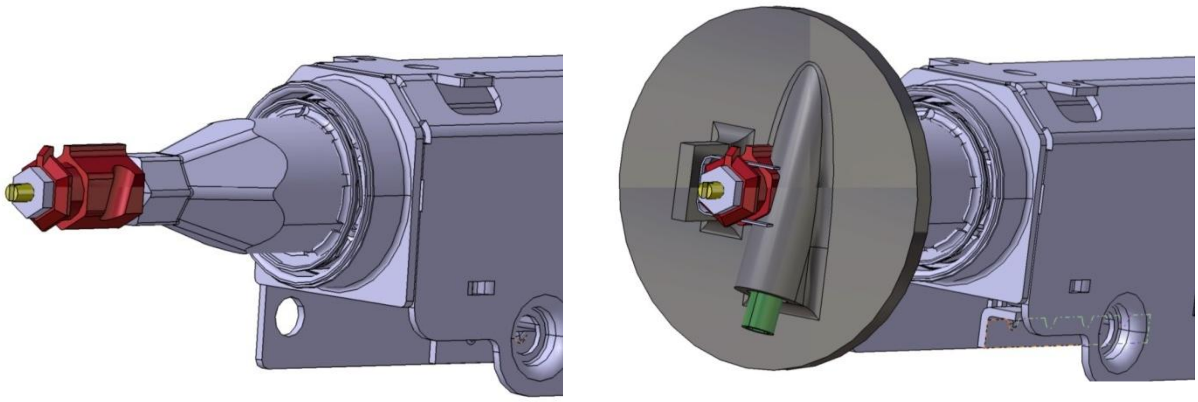


Figure 32: The CAD model of the prototype for the asymmetric steering column pivot with angled screw and Snap-Lock together with the steering wheel interface.

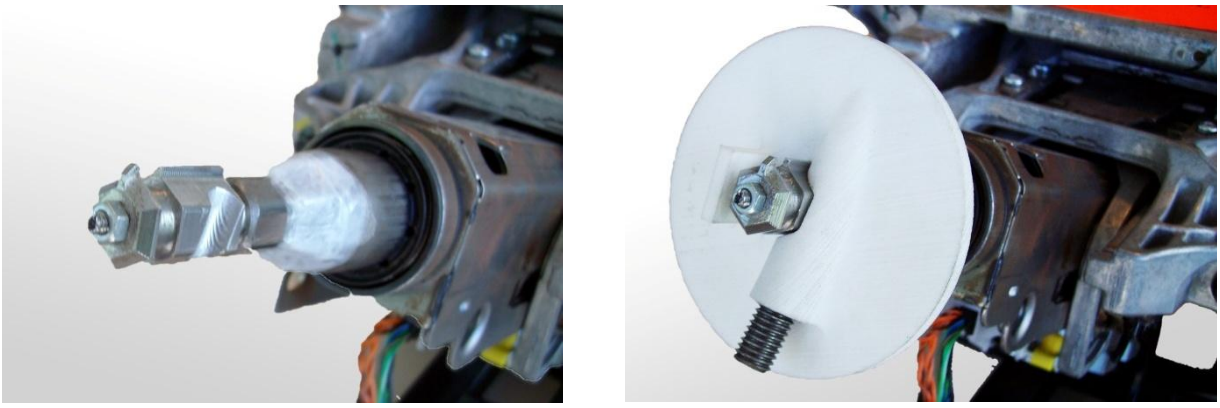


Figure 33: The prototype made according to the CAD models seen in Figure 32, notice that the screw and adapter pivot are made in metal (aluminum) and the steering wheel interface is made in FFF material.

8 EVALUATION OF DETAILED DEVELOPMENT SYSTEM-CONCEPTS

The purpose of this last screening was to evaluate the CAD drawings and prototypes that had been produced during the detailed development stage. The evaluation would result in a decision on which of the developed system-concepts would be the best candidate for final concept.

The detailed development prototype of the flexible connector showed that the fittings between the two connectors work and it was possible to mate the two connectors in different angles to each other. The biggest angled possible for mating the two connectors were approximately 2,5 degrees, which is bigger than the angle between the airbag module and the clockspring.

Testing of the flexibility showed that the latches from the lower plate in the connector, which keeps the springs in right position, were too small and weak and thus could not keep the connectors in the right position. It was decided that a new design was needed that better secured the flexible properties and that also incorporated the locking hooks.

Test of the steering wheel securing prototype showed that the screw seemed to function as a tightening means. However it was decided that a more elaborate prototype completely in metal would be needed to ensure that the interface deformed properly. It was also decided that the solution of the clip function must be changed. The clip did not snap into the groove until the screw was completely attached, which is not the purpose. The clip should snap when the interface adapter plate is first mounted onto the steering column pivot.

The four system-concepts that had been further developed were presented to the project stakeholders in order to come to a decision on which one to choose for final concept. However the decision was not one of the proposed concepts, as expected. Instead it was decided that to maximize the innovative nature of the final concept, a new system-concept was formulated by the stakeholders, combining some of the detailed development system-concepts. The final concept that was decided to go further is illustrated in Figure 34 below. It is essentially system-concept 1421 with a press-pin for the clockspring unlocking. In order to confirm that the new formulated concept met the criteria in the Pugh evaluation and Kesselring scoring matrices satisfyingly, the final concept was evaluated in the same way. The result was that it had equal ranking as system-concept 18 in the Pugh matrix and received third place in the rankings from the Kesselring matrix. See Figure 35 for a portion of the complete evaluation matrix. The complete evaluation and scoring matrices can be found in Appendix G. This analysis concludes that the proposed final concept did meet the criteria satisfyingly and was eligible for further development.

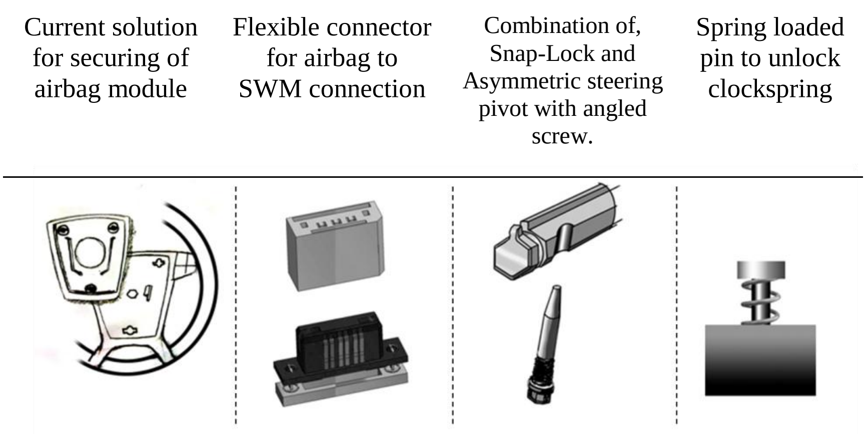


Figure 34: The final concept presented here with its respective sub-concepts included.

Morphological concepts	Pugh Matrix	System-Concept 3	System-Concept 10	System-Concept 11	System-Concept 12	System-Concept 13	System-Concept 14	System-Concept 15	System-Concept 16	System-Concept 17	System-Concept 18	System-Concept 19	System-Concept 20	System-Concept 21	System-Concept 22	System-Concept 1421	Final Concept
The SRS signal to airbag must be resistant to distrubances	few connectors	-	0	0	-	-	0	-	-	0	0	0	0	0	0	0	0
	low risk of connector gnuggning	0	+	-	0	0	+	-	0	+	+	0	+	0	+	+	+
Fastening and securing the steering wheel is crucial to driver safety	Able to verify mounting steering wheel	+	0	0	+	+	+	+	0	+	+	+	+	+	+	+	+
	Low risk of play in z-direction	-	0	0	-	0	+	+	0	+	+	+	+	+	+	+	+
	Handles steering torque	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Able to verify mounting Airbag	-	-	-	0	0	-	-	0	-	-	0	-	0	-	-	-
Feedback to ensure build quality	Resistance to human errors (not easy to forget)	+	+	+	+	0	+	+	0	+	+	+	+	0	+	+	+
	Good Feedback to assembly personnel (sound vision)	+	0	0	0	0	+	+	0	+	+	+	+	+	+	+	+
New design reduces assembly time	Short Assembly time	+	+	+	0	0	+	+	0	+	+	0	+	0	+	+	+
	No additional tools needed	+	+	+	+	0	+	+	0	+	+	+	+	+	+	+	+
	Simplifies assembly operations	+	+	+	+	0	+	+	0	+	+	0	+	+	+	+	+
The locking function of the clockspring	Easy to unlock	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+
	Easy to relock	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+
	Cannot be accidently unlocked	-	+	0	-	+	+	+	+	+	-	-	+	+	+	+	-
	Able to lock in multiple positions	+	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+
Moving parts must not interfere with any functions	Good guidance for loose parts (cables)	-	+	-	0	0	+	-	0	+	+	0	+	0	+	+	+
New design reduces overall cost	Low Number of parts	-	-	0	0	-	-	-	-	-	-	-	-	-	-	-	-
	Manufacturable	+	-	-	0	-	-	0	0	-	-	0	-	0	-	-	-
	Lower Cost	0	-	-	0	-	-	0	-	-	-	0	-	-	-	-	-
Guiding features for fast, easy and correct assembly	Low risk of vibration damping interferance	0	0	-	0	0	0	-	0	0	0	0	0	0	0	0	0
	Good visibility of assembly	-	-	-	0	0	-	-	0	-	-	0	-	0	0	-	-
	Provides possibility for more ergonomic assembly	+	+	+	0	0	-	0	0	0	0	0	0	0	-	0	0
	Many guiding features	+	0	0	+	+	+	+	0	0	+	+	+	+	+	+	+
The design needs to be compatible with future additions to the SW	supports modularity and platform thinking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Provides support for different sequences of assembly	0	0	0	0	0	-	0	0	0	0	0	0	0	-	0	0
One person alone should be able to assemble to complete SW	Criteria: Weight, reach, visibility, complexity of assembly	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Theft protection	Easier to assemable than disassemble	+	+	+	0	+	+	+	0	+	+	+	+	+	+	+	+
	sum +	13	12	6	8	7	15	13	4	14	14	10	15	11	15	15	14
	sum -	7	5	7	3	4	7	7	3	5	6	2	5	2	6	5	6
	sum 0	7	10	14	16	16	5	7	20	8	7	15	7	14	6	7	7
	Total	6	7	-1	5	3	8	6	1	9	8	8	10	9	9	10	8

Figure 35: The evaluation matrix of the system-concepts. Notice the rightmost column which represents the Final concept solution chosen during the detailed development evaluation. Not all system-concepts are shown in this figure, for the complete list, see Appendix H.

9 FINAL CONCEPT

The final concept which was decided during the evaluation of the detailed developed system-concepts needed to be developed further in a number of ways. First of all, new CAD models needed to be produced describing the functions more in detail. Secondly, prototypes needed to be produced in order to further test the functionality of the concept. Lastly the prototypes needed to be tested in accordance with VCC demands on certain parts of the complete steering wheel assembly. In order to thoroughly describe how the final concept will function, an overview of the complete final concept and the assembly procedure of it will first be described. Then, each of the previous four issues that were identified in the concept development stage will be described in detail. Lastly the final concept prototype will be presented and compared to the CAD models.

The complete final concept assembly is shown in Figure 36. The four sub-concepts included in the final concept have been integrated in their respective parts of the assembly. The figure also indicates the basic procedure for how they are to be mounted. The airbag module with its connector is first assembled together with the steering wheel on a pre-assembly station into a one-piece. When this is done the complete one-piece steering wheel is mounted onto the steering column, the Snap-Lock clip confirms that the steering wheel is in its right position and ready to connect to the clockspring. The clockspring locking is released by the act of mounting the steering wheel on the steering column which presses the clockspring release pin inwards. The assembly worker then presses on the airbag module to connect the airbag module to the flexible clockspring connector. When this has been done, the final step is to secure the screw from underneath the steering wheel.

Figure 36: An overview of the final concept assembly. Each of the four sub-concepts included have been integrated into their respective parts.

9.1 Description of final concept: Securing of the steering wheel

The final concept steering wheel securing is illustrated in Figure 37. The illustration shows the new steering column pivot with an asymmetric shape in the form of a key on the top of the steering column pivot [1], the Snap-Lock clip [2] and the conical shaped screw [3].

The key on the top of the steering column pivot [1] has two functions. It is intended to be used by the assembly personnel when aligning the steering column pivot [1] in accordance to the wheels of the car. In order to enable correct assembly of the steering wheel the key has to be pointing upwards when the wheels are in their middle position, steering the car straight forward. The second function is to guide the steering wheel correctly onto the steering column pivot [1]. Since there will only be one possible way to insert the conical screw [3] it is important that the steering wheel, which holds the screw, is mounted in such a way that it is possibly for the screw to enter the angled groove on the side of the steering column pivot. The combination of these two functions adds one more advantage. Even if the steering column pivot [1] is somewhat turned, for instance pointing downwards when arriving at the steering wheel mounting station, the steering wheel can still be mounted without any correction of the steering column pivot. Since the key will always be aligned correctly with the wheels of the car, hence the steering wheel will be mounted correctly even if it is mounted upside down.

The Snap-Lock clip [2] which resides in the steering wheel also has two main functions. The clip provides a type of feedback to the assembly personnel at the assembly station. The feedback is given in the form of the clicking sound which emerges when it is clicked into the groove on the steering column pivot [1]. This click sound informs the personnel that the steering wheel is in place and that it is time to secure the conical screw [3]. If the sound levels of the factory are loud and the click sound cannot be heard, the personnel can simply try to gently detach the steering wheel from the steering column again. If the clip has been placed in the right position the personnel will feel a resistance and it will not be possible to detach the steering wheel.

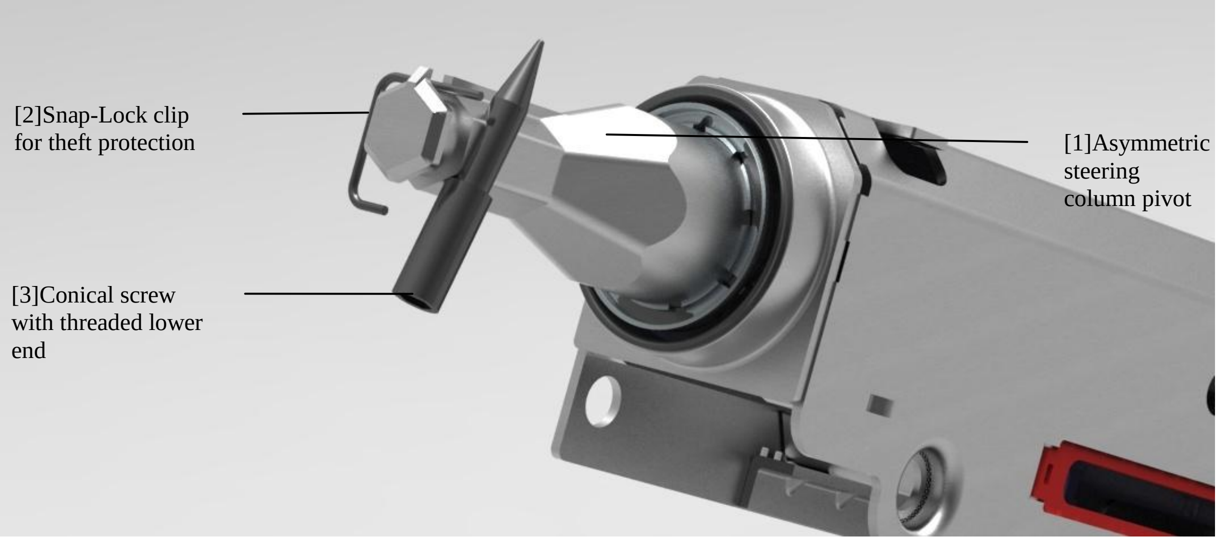


Figure 37: The final concept securing of the steering wheel, the illustration shows the steering column and steering column pivot isolated together with the conical shaped screw and Snap-Lock clip residing in the steering wheel.

The second function of the Snap-Lock clip [2] is to provide a theft protection of the steering wheel. Since the conical screw which secures the steering wheel to the steering column pivot [1] is accessible from the outside of the steering wheel there needs to be something that prevents a potential thief to remove the steering wheel even after the screw has been extracted. The Snap-Lock clip [2] does just that. In order to detach the steering wheel from the steering column pivot [1] one needs to first extract the screw and then release the clip. Releasing the clip is done through a hole on the backside of the steering wheel, see Figure 38 . This hole is however covered by the plastic covers around the steering column when the steering wheel is in its mid position. In order to reach the hole, the steering wheel needs to be turned 90 degrees counterclockwise from its mid position. In order to do this the steering column lock needs to be released, which is done with the ignition key. Consequently, the steering wheel cannot be removed without the ignition key.

Figure 39 illustrates the inside of the steering wheel when mounted onto the steering column pivot. Observe that the DAB has been hidden in this figure, it would normally cover the area shown here. The steering wheel is moulded to its shape and is made of a magnesium aluminum alloy. The main differences from the current product is the insert body for the conical screw [4] which has been added into the shape and it is to be molded together with the rest of the features on the steering wheel. Another addition is the groove for the Snap-Lock clip [5] which is also to be molded together with the rest of the features. Before mounting the steering wheel onto the steering column pivot the Snap-Lock clip [2] and concial shaped screw [3] is inserted in the steering wheel. This can be done either at VCC or by the supplier that manufactures the steering wheel before delivering it to VCC. When the clip and conical screw has been inserted, the DAB is mounted into the steering wheel.

Figure 38: Final concept; securing of steering wheel: The arrow illustrates the position of the hole on the backside of the steering wheel were the Snap-Lock clip can be released. The hole is normally covered by two plastic covers.

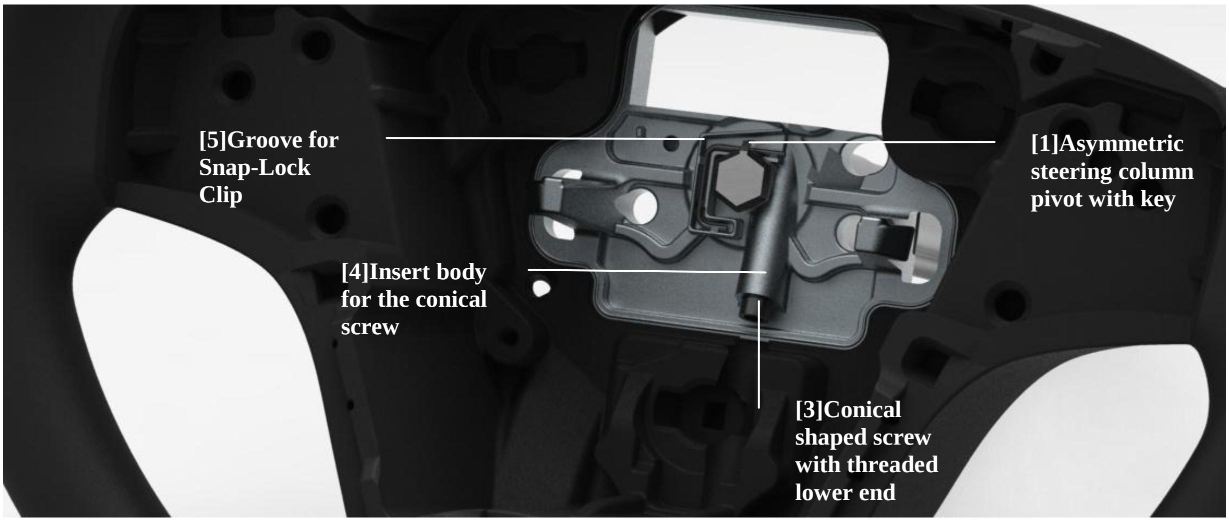


Figure 39: Final concept; securing of steering wheel: Inside of the steering wheel when mounted onto the steering column pivot.

9.2 Description of final concept: Airbag to SWM connection

The final concept for the airbag to SWM connection resulted in a flexible connector designed by the authors. The basic principle was to combine the advantages of a rigid connector without cables and the flexibility of connectors with cables. Since the airbag module is flexible because of the horn function integrated in it, the connection between the airbag module and the SWM needs to be flexible as well. However as the connector is to be blind mated at the assembly station of the steering wheel, it needs to be controlled and fairly rigid in order to minimize the risk for failed connection.

The final concept can be seen in Figure 40. It consists of two parts which are to be mated together when assembling the steering wheel. One connector is resident in the DAB [1] and the other is resident in the SWM [2]. Both of them have some common features, for instance they are both chamfered at the top in order to align them correctly if they are mated slightly offset from each other. They also feature the same sort of locking hooks [3], these hooks have the purpose of locking the connectors together when they have been mated, this is important in order to prevent that the connection surfaces of the terminals glide or vibrate. Such vibrations or gliding can disturb the signal between the SRS and DAB and can also cause harm to the terminals and wear out the connection surface.

The locking-hooks [3] are designed to ensure that the connectors are easier to mate than unmate, thus there is no need for any extra clip or lock between the connectors. A traditional clip lock between the connectors which can be removed by using ones fingers is not possible to use in this concept since it will not be possible to reach the connector in any way when the DAB has been mounted onto the steering wheel. Thus it has to disconnect by pulling it apart.

A unique feature for the SWM connector [2] is the flexible housing [4] which is connected to the clockspring. Inside this housing there are springs that enable the SWM connector [2] to move about in all directions in a controlled manner, resembling a joystick. In order to transfer the signal, the SWM connector [2] does have cables that are protected by the flexible housing [4] which makes it possible to flex in all directions. A unique feature to the DAB connector [1] is the use of short circuit connectors [5] in it. These short circuit connectors [5] are used mainly together with pyrotechnical devices such as airbags. When the DAB is not connected to any power source the short circuit connectors [5] short circuits the DAB connection which prevents any static electricity to deploy the airbag accidentally. The short circuit connectors [5] are therefore only situated in the DAB connector [1]. When the connectors [1] and [2] are mated the short circuit connectors [5] are moved away by the SWM connector [2], enabling the terminals [6] from the SWM to connect with the terminals on the DAB connector [1].

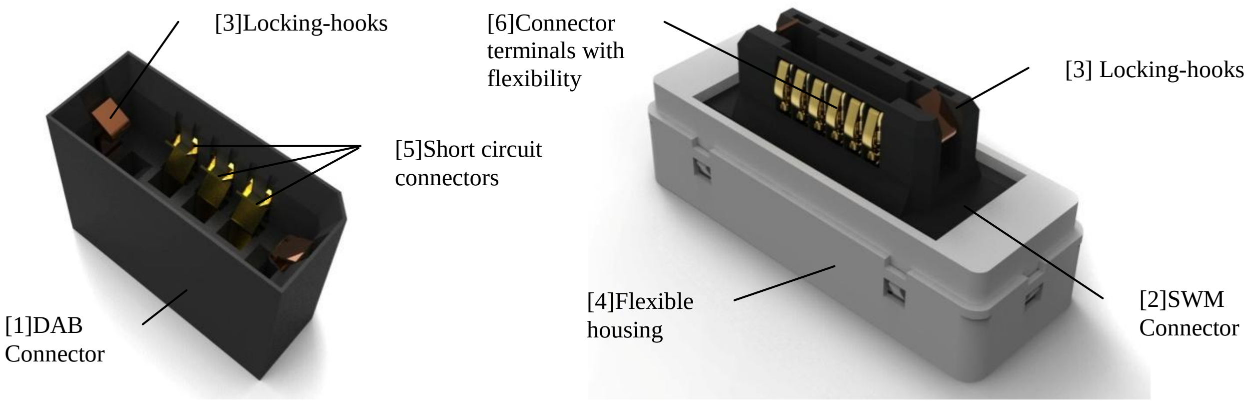


Figure 40: Final concept; airbag to SWM connection. Flexible connector assembly, the connector to the left is residing in the DAB and the connector to the right is residing in the SWM.

In order to clarify how the locking-hooks [3] on both connectors function, the connector assembly has been illustrated with X-ray vision, showing only the terminals and locking-hooks [3], see Figure 41. The slope of the locking hooks [3] will gently slide the locking hooks in the SWM connector [2] inwards towards the center of the connector, until they are pressed together entirely. At this point the locking hooks [3] in the SWM connector [2] will bounce back and lock in with the locking-hooks [3] from the DAB connector [1]. The almost horizontal slope of the locking-hooks [3] in this position will provide a resistance when the two connectors are to be pulled apart.

Figure 42 illustrates how the connectors are supposed to be attached to the DAB and SWM. The SWM connector [2] is attached via the flexible housing [4] onto the clockspring which in turn is connected to the SWM. The DAB connector [1] is molded into the plastic back plate of the DAB. By molding the connector together with the back plate the position of the connector will be more accurate compared to if the connector was made as a separate part and then attached to the back plate. Observe that in the final concept design of the DAB, the cover plate and cables have been replaced by the flexible connector.

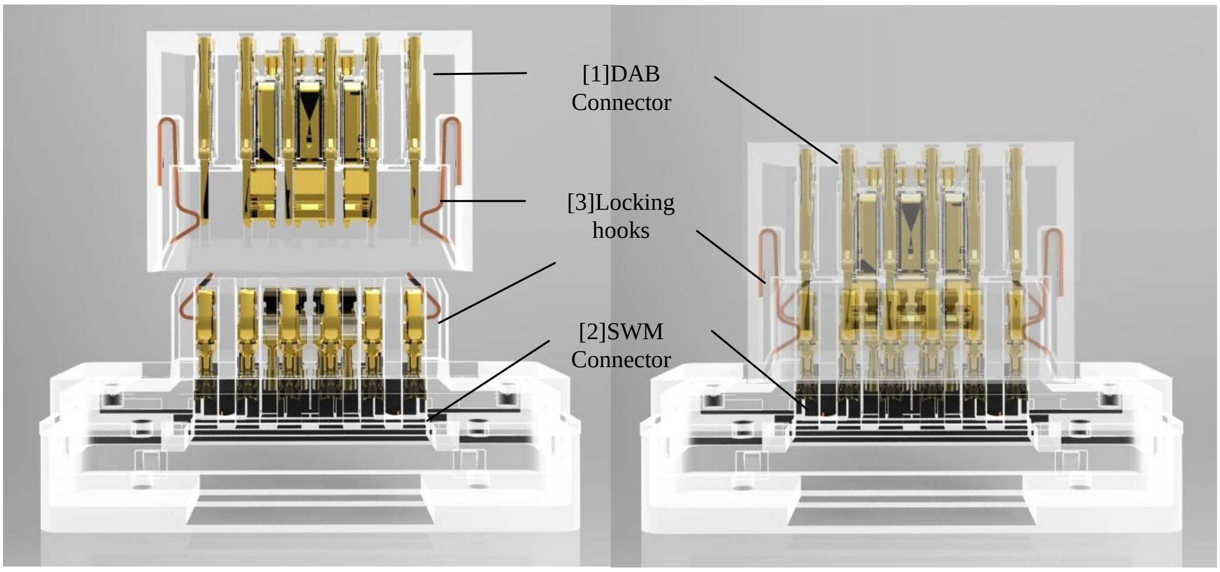
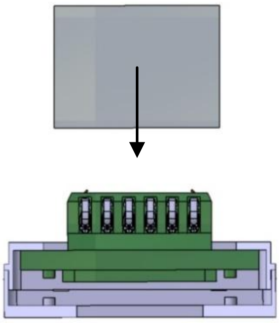


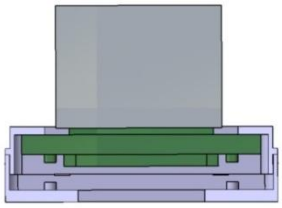
Figure 41: Final concept; airbag to SWM connection, X-ray illustration of the flexible connector before and after connection, notice the locking hooks which are hooked together when the two connectors are assembled.

Figure 42: Final concept; airbag to SWM connection, the flexible connectors residing in their respective modules. DAB to the left and SWM (clockspring) to the right.

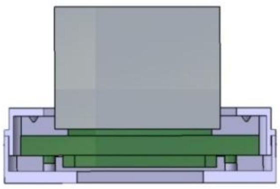
The figure sequence on this page illustrates what happens inside the flexible housing when the airbag is connected to the SWM. The different connectors have been given different colors to better distinguish them from each other.



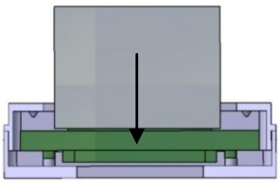
Connector from DAB is aligned with connector from SWM and are pressed together.



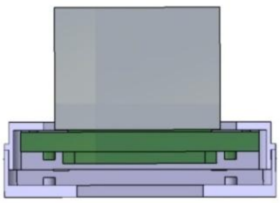
Connector from DAB is connected with connector from SWM but not locked.



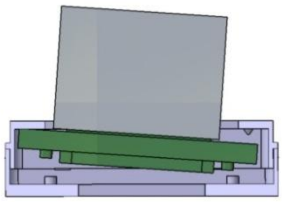
The DAB and SWM connectors move together towards the bottom of the SWM connector housing.



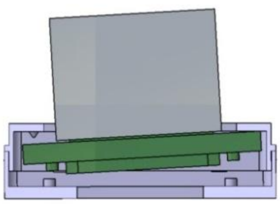
When the two connectors have reached the bottom, the DAB is pressed further down in order to lock the DAB and SWM together by the hooks on the inside.



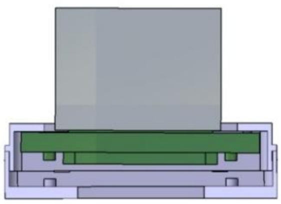
The two locked connectors are now moving together upwards to the connectors steady state.



From the steady state, the assembly can flex when the horn is used.



The housing has some extra space for the connector to move about inside it, and guiding features on the inside of the housing to keep it steady when it is not flexing.



When the connectors are in their steady state, the springs in the housing are steadily pressing the connectors upwards which prevents unnecessary vibrations.

9.3 Description of final concept: Airbag mounting

It was decided in the evaluation of the detailed development concepts that the best solution for mounting of the airbag module was actually the currently used one, see Figure 43. The airbag module as it is today uses flexible feet and latches to click the airbag into place. This means that there was no extra development work done to the airbag module mounting.

Figure 43: Final concept; airbag mounting, the final concept idea utilizes the same features as the solution used in current airbag modules, flexible feet and latches.

9.4 Description of final concept: Clockspring locking

The clockspring locking function for the final concept is a spring loaded pin which will release the clockspring when the pin is pressed down, see Figure 44. The idea is not new, it has been implemented by other car manufacturers before but it is a simple solution with good effect. Since there is no possibility for the assembly personnel to reach the clockspring when the steering wheel has been mounted together with DAB and other features the clockspring has to release itself automatically. When the steering wheel is mounted on the steering column pivot, the steering wheel will press down the spring loaded pin on the clockspring and thus release it. When the steering wheel is removed, for instance during service or repair, the clockspring will lock itself since the spring loaded pin will push up again.

Figure 44: Final concept; clockspring locking. A spring loaded pin which is pressed down when the steering wheel is mounted into the car. When pressing down the pin the clockspring can rotate. When the pin is pushed up again, the clockspring locks itself.

9.5 Final concept prototype

It is very important to verify the properties of the final concept with tests and to do so, prototypes need to be manufactured. In this project two prototypes were made. The first one was a prototype for the flexible connector, where the flexibility and mating operations were to be tested. The second prototype was made to test the securing of the steering wheel to the steering column pivot.

9.5.1 Prototype of the flexible connector

Since the first tests with the initial prototype identified some shortcomings in the flexibility of the flexible connector a new design was developed in order to improve it. Two different pieces were used this second time also, one flexible and one fixed. Many features were reused in this second prototype but in order to eliminate the undesirable properties of the first prototype, see Chapter 8, an alteration of the first prototype was made. Instead of the underlying plate with latches and springs, the springs and flexible part of the connector was put into a house. This should provide more control over the connector and the springs.

For the new prototype, see Figure 45, standard electrical terminals were used in order to better represent the finished product. Two different electrical terminals were used, one thin and one wide. The wide electrical terminal was located in the flexible part and the thin electrical terminals were located in the fixed connector. The wide electrical terminals provide some flexibility towards the thin electrical terminal due to their shape which resembles leaf springs. This flexibility together with the different size of the electrical terminals ensures that they always are in contact with each other and that a steady connection is maintained.

These new electrical terminals requires a little bit more space which means that the connectors hade to grow in size. This is however not a problem since it makes the connectors more robust and bigger chamfers could be added to the fixed connector. The bigger size does add material though and thus also add some cost.

In this prototype, the locking hooks were implemented. This was done to test the properties of the different slopes of the locking hooks and to make sure the locking hooks worked as intentioned. As described in Chapter 9.2, the intention of the locking hooks is to provide a greater unmating force than the mating force.

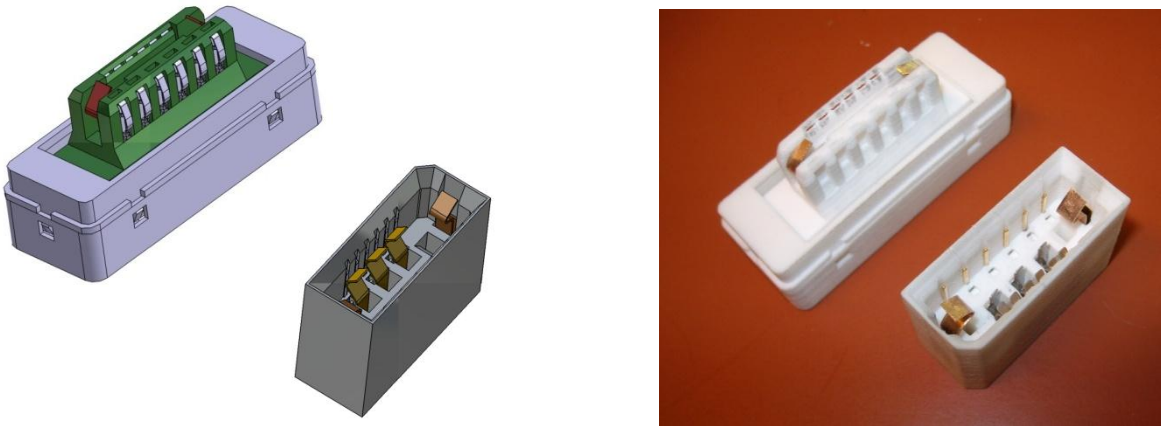


Figure 45: The modified prototype for the flexible connector, seen as a CAD model to the left and the actual prototype to the right. Main differences from the initial prototype are that locking hooks, terminals and short circuit connectors have been added.

9.5.2 Prototype of asymmetric steering column pivot with angled screw and Snap-Lock

This second prototype of the steering wheel securing final concept was made in aluminum instead of FFF material, see Figure 46 and Figure 47. The prototype included both the steering column pivot and the interface of the steering wheel. With the parts made in metal instead of FFF material it was possible to conduct more reliable tests on the prototype. The most important test was to ensure that the axial force provided from the angled screw deforms the interface so the risk of play is minimized. The screw has been redesigned in order to make it possible to secure it using a wrench. With a wrench, a higher torque can be put on the screw compared to a screwdriver and thus provides a more secure screw joint.

The new design of the clip was introduced in the steering wheel part of this prototype. Instead of a U-shaped clip, an L-shaped clip was implemented. A new attachment in the form of two small screws was made to have an easier insertion and fastening of the clip. With this design it was possible to test if an L-shape was sufficient to secure the steering wheel and if the clip provided enough feedback to the assembly personnel. The actual product would probably not have these two screws to secure the clip

A new steering column pivot was also designed. The backside of this part had a set of four screw holes where different adapters could be attached. In Figure 47 an adapter is attached to make it possible to place the prototype in a vice when testing it. This adapter could be changed to one with an interface that match the current steering wheel and could then be mounted in a car.

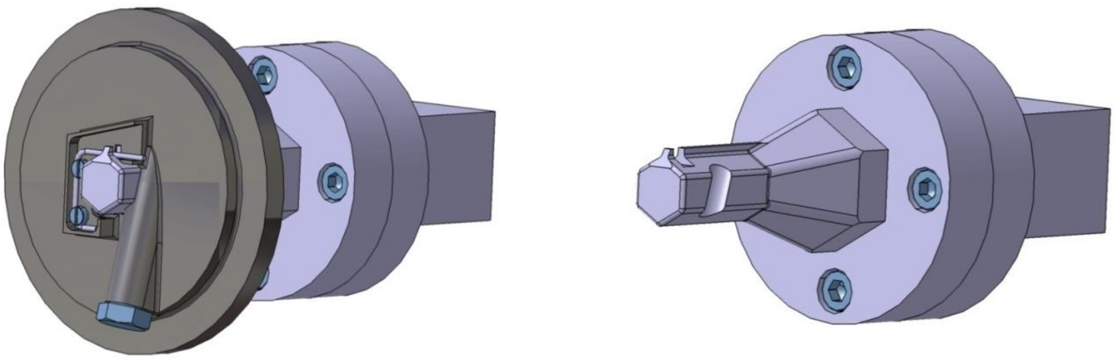


Figure 46: The modified prototype for the steering wheel securing. This figure illustrates the CAD model, it has a new clip but the rest of it is very much like the initial prototype. It has had some modifications made to ease the production process of it since it was supposed to be 3D milled out of aluminum.

Figure 47: The actual prototype for the steering wheel securing made out of aluminum. The left picture shows the new prototype inserted into a steering wheel, which was done in order to test the interface properly. The picture to the right shows the steering column pivot which has a replaceable back plate that can be removed with screws. This back plate can be changed to another one which enables the steering column pivot to be inserted into a car with the current steering wheel assembly.

10 CLOSING AND REVIEW

This chapter will discuss the outcome of the project and future prospects. The goals that were stated in the beginning as a result of the pre-study will be compared to the end result of the project work and the overall effect of the final concept solution will be discussed. The chapter will be ended with some conclusions and recommendations for future work

10.1 RESULTS

The results of the project will in this chapter be compared to the goals set during the first screening, see Chapter 4. The goals of the project are however not the only aspect to review, there were also a set of requirements and issues that needed to be taken into consideration during the project, the list of these requirements and issues can be viewed in Table 6, Chapter 3.7.3 and Table 5, Chapter 3.7.2 respectively.

Overall, the result was satisfying compared to the set goals. The objective of redesigning the interfaces of the steering wheel assembly in order to enable a one-piece assembly was met. All of the interfaces, except the airbag mounting interface, were changed. The reason for letting the airbag module remain as it was, was that it already had a sort of snap-on mounting which fitted well with the rest of the one-piece assembly strategy. The new interfaces required some modifications to the current steering wheel assembly but they were still fully able to manufacture and finance according to the cost estimators and manufacturing engineers. The redesign and modifications made to the interface however made the assembly slightly more expensive to manufacture, this was a minor increase in cost though. The goal was to reduce overall cost, taking personnel salary, manufacturing cost, material cost and other costs into consideration. The end result then was that the savings in personnel cost and overall production exceeded the increase in cost of production and thus reduces the total cost of the assembly. The greatest savings were made on the production line, where a number of tools and steps could be discarded due to the idea of having a pre-assembly station which is not connected to the production line. This pre-assembly could even be outsourced to the suppliers but no reflection has been made about the possible savings or cost increase such an outsourcing could result in. Because of the use of a pre-assembly station not connected to the production line, the time pressure on such a station would be low. The less stressful environment of the pre-assembly station would make it possible for the assembly personnel to take their time during the assembly procedure and really make sure that everything fits well and that the steering wheel and airbag function properly before they are inserted into the car. This could be translated into an increase of quality assurance which was one of the goals to meet during this project. The quality assurance is further confirmed by the calculation of the Robust index which indicates how sensitive the assembly is to failure. The current assembly process has a Robust Index of 3.8, and the new assembly process has a Robust Index of 2.5. On a scale from 0 to 9, were 0-2 is “high robustness”, 2.1 to 3.5 is “medium robustness” and 3.6 to 9 is “low robustness”. With the proposed final concept the assembly process goes from “low” to “medium” compared to the current solution.

When it comes to the project work that was carried out there was a number of goals that were to be met. The planning and execution of the project was made by using known theories from the area of product development. By using these theories, methods and strategies the project work became structured and easy to follow even if it was a bit chaotic in the beginning. The said chaos was however needed since it is important during such a product development project to keep an open mind and look for all kinds of possibilities and solutions that can be of any use. The brainstorming and evaluation procedures for example, resulted in a number of different sub-concepts which have been presented in this report in order to store the knowledge for future projects. Thus the goals related to the project work structure were also met.

The final concept that has been proposed in this report has many similarities with the current solution, this is not unintentional. In order to minimize development cost and to be able to produce a prototype at the end of the project the design of the final concept needed to resemble the current solution as much as possible. This is also true for any extra parts added, they needed to be standardized parts to some degree since it saves a lot of development cost by using products that have already been tested and verified. The automotive industry is very sensitive to regulations, laws and customer demands just to name a few factors. Thus it is always desirable to reuse parts, materials and ideas that have already been developed to some degree in order to save development cost. With this said it is important to understand that the actual physical design of the final concept presented in this project is not the most important one. The actual final product could look completely different depending on other criteria. Since the next generation of steering wheels that will actually implement the ideas and concepts stated in this report is to be produced several years from the current date, the design of the next generation will probably also be altered and features or functions will probably be added in order to meet future customer needs. The design presented in this report is therefore a mere example of how it could look and has been designed in such a way to simplify prototype production.

The prototype then was produced using both rapid prototyping methods and more complex methods such as 3D milling of aluminum, in order to produce a more realistic prototype that could be tested with the same criteria as used for a mass manufactured steering wheel.

The DFA analysis of the current steering wheel assembly showed that many steps were made inside the car. With the final concept however, the steps made inside the car were minimized and steps that had been eliminated were primarily those that had bad reachability, insertion and tight tolerances. Some of the steps were moved to the pre-assembly station outside the car instead and some were eliminated. An example of how the new design has improved the DFA score is the implementation of the Snap-Lock clip. The Snap-Lock clip in the final concept design ensures that the steering wheel sits in its place when it has been attached to the steering column, this feature gives the assembly a higher DFA score compared to the current steering wheel assembly. The aggregated score for the assembly station on the line has been increased with 18 percentage points and stays on an aggregated score of 92 %, where the optimum is 100 %. The aggregated time has been decreased with 130 percentages point to a total of 150% for the final concept of the assembly line. The optimum score is 100 %. 100 % means that the assembly procedure is using the time most efficiently and that the capacity of the station is at its maximum. See Appendix I for the final concept DFA results.

Two steps have been moved to the pre-assembly station, the insertion of the airbag and the attachment of the screw. These two steps are however more effective than the other ones and thus increases the overall efficiency of the pre-assembly station. The result of this is that the score move towards the optimum. The aggregated score has been increased with three percentages point to 75% and the aggregated time has been decreased with one percentages point to 252%.

These results indicate that the final concept design has not only increased the value of the steps but also the effective time has been increased for both assembly operations even though steps has been moved from one part of the assembly to the other. The most important result is the optimization inside the car, where the risk of incorrect assembly operation can lead to a total stop of the line, this risk has been reduced with the final concept solution.

The DFA analysis is built on subjective judgment and other evaluations have to be made but it can be used as a guide to recognize which steps that can be optimized and which can be eliminated.

Continuing with the overall results of the project, the requirements stated during the pre-study of the project was also to be respected. In Table 8 below the end result of those requirements have been inserted in the rightmost column. A "Yes" indicates that the requirement was met and a "No" indicates that it was not. The term "Not measured" means that it was not possible to measure the requirement at the end of the project. The requirements that received a "No" were the wanted reduction of the total weight and the manufacturing cost. The total weight of the steering wheel was not reduced but also not increased significantly thus this had little or no impact on the performance of the assembly. A slight increase in manufacturing cost was identified and will be discussed in detail in the next chapter.

Table 8: Requirement list established during the pre-study, the result of the project has been added in the rightmost column, ▽= Reduce, △= Increase, X = Target value.

Functional Requirements	**Direction of change or target value**	**Relative weight**	**Result**
Manual connecting operations (#)	▽	8,9	Yes
Number of guiding elements (#)	△	8,9	Yes
Assembly time (t)	▽	8,7	Yes
Number of connectors in circuit (#)	▽	7,1	Yes
Pulling force normal to the steering wheel(N)	X	6,7	Not measured
Length of cable slack (mm)	▽	6,7	Yes
Signal input/output variation (V)	▽	6,7	Not measured
Number of assembly operations outside the line (#)	△	5,9	Yes
Evaluation score of functionality (score)	△	5,0	Not measured
Part manufacturing cost (SEK)	▽	5,0	No
Ratio between variants and parts (variants/parts)	△	4,3	Yes
DFA Score (score)	△	3,9	Yes
Ratio between current number of steps and new number of steps in assembly (steps/new steps)	△	3,5	Yes
Input current to steering wheel (A)	X	3,3	Yes
Number of audio signals for feedback per operation (#)	X	3,3	Not measured
Steering column vibration (Hz)	▽	3,0	Not measured
Total weight (kg)	▽	3,0	No
Maximum torque on steering wheel (N)	X	2,2	Not measured
Sound level of audio feedback (dB)	△	2,2	Not measured
Material cost (SEK)	▽	1,7	Yes

10.2 Part manufacturing and cost

The manufacturing possibilities and procedures will be affected by the demands of the suppliers that will actually manufacture the different parts included in the steering wheel assembly. If the parts included in the assembly can be sold to other industries or car manufacturers, the suppliers will be able to provide better prices to VCC since they can produce larger volumes of the parts. The cost estimations made in this chapter has been done with the assistance of VCC's own cost estimators who are experts in this field and has enough experience to assume certain possible volumes of parts and their manufacturing costs. Overall, the complete concept would, according to the estimations, be a bit more expensive since it requires new methods of manufacturing and new tooling. However, because of the other savings the concept provides, these manufacturing costs can be disregarded. An overview of the cost calculation result can be viewed in Table 9 where the current solution cost is compared with the proposed final concept solution.

10.2.1 Steering wheel securing interface costs

The current steering wheel frame is made by casting. The casted frame is covered with foam to get the desired shape. Finally the steering wheel rim is covered with leather. The final concept follows the same procedure with some modification. The frame of the final concept has to be processed by milling and thread cutting. Due to high tolerances this cannot be made solely by casting. Benefits from these extra processing steps in the manufacturing is the possibility of processing other features of the steering wheel frame to a very low cost and thus increase the tolerances on those features. Such features could be the hexagon interface between the steering wheel and the steering column pivot.

The final concept requires a new screw. A standard screw is not possible to use due to the special shape of the screw. Two types of manufacturing processes could be possible. The first one is to manufacture a screw from the beginning with the desired feature or as a second alternative, modify an existing screw. Compared to a standard screw this type of special screw is more expensive.

Another new feature, which is not existent in the current solution, is the clip. Due to the size of this clip, the material and manufacturing costs are very low. The clip is made from a wire, cut in proper length and folded into the desired shape.

A completely new design of the steering column is needed to make the final concept possible. The changes will only affect the steering column pivot and the rest of the steering column will remain the same. A more complex manufacturing process is however needed to accomplish all desired features. The steering column pivot is a solid piece that can be milled into the hexagon shape with the key. Two grooves, one for the screw and one for the clip, have to be integrated which requires more steps in the manufacturing process. All these steps add cost to the part and because of these steps the final concept solution will be more expensive than the current one.

10.2.2 Airbag to SWM connection

For the electrical parts of the final concept some savings are made because of the reduction of the cover plate in the airbag module. The cover plate is an expensive solution which has been a quick fix solution late in the product development process. With the final concept this plate can be eliminated. Instead, a fixed connector is molded into the frame of the airbag module. This technique eliminates tolerance issues that could have appeared if a stand-alone connector was to be fitted into a slot in the frame. The cost for manufacturing this new airbag module frame will not increase, however it requires testing to verify the reliability of the connection.

The small cable from the clockspring is replaced with the flexible connector. All electrical components in the steering wheel will be provided with electricity through this flexible connector via the clockspring. The housing surrounding the flexible connector is molded into the center part of the clockspring. The flexible connector and the housing, preventing it from detaching from the springs, are molded in separate molding tools. Because of the number of components and more complex shapes of the connector the cost will increase compared to the current solution.

A cost estimation of the two connectors is hard to do because of the early stage in the development. It can however be said that the overall cost of the two connectors will not exceed the savings from the reduction of the cover plate, thus the flexible connectors will either save costs or maintain the current costs.

10.2.3 Clockspring release

The final concept requires an automated release of the clockspring. There are a number of different solutions for this on the market already. Therefore, implementing this function into a clockspring using solutions on the market today will not be expensive. Since this project has focused less on developing the final concept for the clockspring unlocking function, this will be left to the suppliers of VCC to investigate further.

Table 9: Overall result of cost estimation, the current solution is compared to the final concept.

	Current solution	Final concept	Changes needed	ΔCost
Connector details DAB	Cover plate		Yes	-X SEK
	Connector for Airbag	New male connector combining airbag, switch pack and horn	Yes	Not more than cover plate saving
	Connectors and cables for switch packs, horn and ground	Connectors and cables for switch packs, horn and ground		0
	Cables for inflator	Cables for inflator		0
	Cables for switch packs and horn	Cables for switch packs and horn		0
	Frame for Airbag and inflator	Altered frame for Airbag and inflator	Yes	0
Connector details SWM	"Pigtail" for Airbag		Yes	0
	Female connector	New female connector combining airbag, switch pack and horn	Yes	Not more then cover plate saving
Connector details steering wheel	Steering wheel	Altered steering wheel	Yes	0
Interface details steering wheel	Steering wheel	Altered steering wheel	Yes	X SEK
	Securing screw	New securing screw	Yes	X SEK
		Clip	Yes	X SEK
Interface details steering column	Steering column	Altered steering column	Yes	
Miscellaneous	Screw for release of clockspring	Automated release of clockspring	Yes	

10.3 ESTIMATED ASSEMBLY TIME OF FINAL CONCEPT

To verify how much time that is needed to assemble the final concept assembly, a comparison with the current steering wheel assembly was made. These time units only takes the effective working time into consideration and the time for the personnel to for example move around or grab a tool, are not included. The assembly can be divided into two different stations, the pre-assembly station and the line assembly. All the steps required to assemble the steering wheel can be seen in Table 10.

On the pre-assembly station two steps are added, placing the securing screw so it can be tightened later and the mounting of the airbag module in the steering wheel. These two steps increase the assembly time on the pre-assembly station with 190 TMU (6,8 seconds).

When the pre-assembly has been made, the steering wheel is moved to the line assembly. The number of steps here has been reduced from eleven to three. The remaining steps are; the mounting of the steering wheel onto the steering column pivot, pressing on the airbag module to connect the flexible connector and lastly to secure and tighten the angled screw. With only three steps left, the assembly time has decreased with 1075 TMU (38,7 seconds).

A total time saving of 855 TMU (31,9 seconds) has been made for the complete assembly of the steering wheel and a reduction has been made from seventeen steps to eleven steps. The three biggest time savings are made in the following categories;

- Moving and connecting cables and connectors (440 TMU)
- Releasing the clockspring screw (220 TMU)
- Adjusting the steering column and turning the steering wheel (270 TMU)

Table 10: Comparison between the current steering wheel assembly operations and the final concept assembly operations.

	Current solution	Tool needed	TMU	Final concept	Tool needed	TMU
Preassembly	Place steering wheel in fixture			Place steering wheel in fixture		
	Mount cables for switch packs		310	Mount cables for switch packs		310
	Mount switch pack left	Yes	200	Mount switch pack left	Yes	200
	Mount switch pack right	Yes	200	Mount switch pack right	Yes	200
	Secure and fix cables	Yes	340	Secure and fix cables	Yes	340

	Mount deco		330	Mount deco		330
				Place screw		120
				Mount airbag module		70
Total on preassembly station	6 steps		1050	8 steps		1240
Assembly line	Adjust steering column	Yes	150	Mount steering wheel		95
	Bring cables though steering wheel		155	Press on airbag module		45
	Mount steering wheel		95	Secure screw	Yes	210
	Place screw		120			
	Release locking screw for clockspring	Yes	220			
	Move cables		45			
	Secure screw	Yes	210			
	Turn steering wheel 180 degree		120			
	Connect switch packs cables to SWM		165			
	Connect cable to DAB		75			
	Mount DAB		70			
Total on assembly line	11steps		1425	3steps		350
Total	**17 steps**		**2475**	**11steps**		**1590**

10.4 ESTIMATED TOTAL PERSONNEL COST

The total assembly time saving of the final concept assembly has been determined to be 855 TMU. An estimation of how much this time saving can reduce personnel cost for the steering wheel assembly stage can be made. In this estimation, the current tempo of the line and the number of shifts has a big influence: Changes in these two factors can change the result significantly.

The average assembly time per person on an assembly stage is approximately 2000 TMU. If the time saving is 855 TMU it means that 0.43 persons are not needed on the assembly stage. However 0.43 of a person cannot be removed but it gives free time which can be used to do something else on the assembly line station.

According to VCC, one person costs X SEK per year. If 0.43 person is not needed the amount saved is 0.43*X SEK per year and per shift of work. With these calculations and considering that VCC has two manufacturing factories and several shifts, the result is a saving of 0.43*4X SEK per year for VCC in personnel cost only.

Calculations have also been made on how much is saved per car due to this decrease in assembly time, however due to confidentiality the exact savings cannot be presented.

10.5 DISCUSSION

The result from this project has been a complete new assembly method for a steering wheel. According to VCC and based on the research done by the authors there are no known car manufacturers that uses a similar method today. It has been shown in this report that great winnings can be made with a concept like the proposed final concept. The cost savings are of course important but many other winnings can be made that indirectly result in cost savings. Some of those winnings are;

- Quality improvement, which results in less correction to the car after complete assembly.
- Improved ergonomic environment for assembly personnel, which results in less stress and better working conditions.

VCC can be the first car manufacturer implementing a one-piece assembly for the steering wheel. The advantage VCC has on its competitors is that these solutions are protected with two patents, which is a result of this project. This means that other car manufacturer has to develop their own way of doing a one-piece assembly.

The final concept has been developed to fit the current steering wheel as much as possible. There have been many reasons for this. The next generation steering wheel is in its initial phase of the development and therefore it is not possible to say how the final design of the steering wheel will look like. Hence it was easier to show that these solutions were possible to integrate in the current steering wheel and it can be assumed that it is then possible to integrate it in a completely new design. The current steering wheel has many advantages and it can be assumed that VCC wants to keep these advantages for the next generation steering wheel as well.

The project has been conducted from a mechanical designing perspective and it can be discussed if the result has been the same if the project has been done from another perspective, by for instance a manufacturing perspective. It can be said that the goal had not been different since the manufacturing department of VCC has had the same interest of doing a one-piece assembly. It had however been hard to implement the required design changes needed if the project had been conducted under the manufacturing department of VCC.

Decisions in this project have been made on objective judgment as far as possible. The different sub-concepts have been scored with equal judgment and thus no preferential sub-concept could move through a screening. During the project it was of course necessary to let the stakeholders be involved in the decision-making. To minimize the effect of a subjective judgment from the stakeholders, the authors developed, from an objective perspective, options in the form of concepts that were suitable for the project goals. If a new option was suggested by the stakeholders, that had not been objectively judged, this option was examined and judged in the same way as the previous options were. This gives a more reliable result.

Working with a project that has involved many different departments of a big company as VCC, has been a challenge. In some cases it has been hard to meet the person with the right information and sometime no one knows who has the right information. The decision-making is sometimes slow and it demands a lot of bureaucracy and paper work. Due to the nature of this project, being a university master thesis, it has been possible to sometimes go round this bureaucracy, which has resulted in a quicker progress for the project.

When it comes to the choosing of the final concept it is important to realize that the final concept is not the only solution that could work for this project's purpose. During the course of the project many sub- and system-concepts were developed and investigated and according to the objective investigations of the system-concepts the final concept is actually not the absolute best one, though it is one of the best. However there are more aspects than the ones in the objective investigations to take into consideration when choosing the final concept such as current technology level, perceived value and budget to name a few. These aspects have influenced the choosing of the final concept in this project.

10.6 Conclusions

The development in this project has followed theories and methods in the subject of product development. It has been shown during the project that these methods can be of use and are helpful to bring order to the chaos that seems to occur in the beginning of the project. Using a structured way of working improves the end-result of the project. Though it has been seen that there are many theories on how to structure the beginning of the work, how to collect data from stakeholders and how to generate the initial ideas it is realized that when this first stage is passed, the amount of available theories and methods are reduced substantially. It seems that the industry world is better at providing methods and strategies for the industrialization part of a product development project. This is necessarily not negative in any way, it does however show that the industry and the academic world have a lot to learn from each other.

The project was started with an idea of improving the assembly of the steering wheel. It was thus important to know what an improvement could be, which in turn meant that it was important to recognize the stakeholder needs. By conducting some research on the subject it was possible to state some stakeholder needs and with those needs formulate demands on the end-product. From the result, Chapter 10.1, it has been shown that the final-concept fulfills almost all the requirements. Noteworthy is the fact that the requirements that were not fulfilled had a lower score and were less prioritized.

With the final concept, a higher quality of the final product could be achieved. Less stops on the production line, less complaints from end customers and better ergonomic situation for assembly personal are some of the benefits from this solution, all this to a lower cost than the current solution.

To verify if an improvement has been achieved from a VCC point of view, the author let the manufacturing department of VCC calculate the Robust index in order to compare the new assembly process with the old one. The Robust index was improved by 66% compared to the current steering wheel assembly. This means that the new final concept is less sensitive to failures in the assembly process and needs less control and quality checks.

The above discussed factors show a positive trend of the final concept and that there is much to win by implementing this solution but of course there are some aspects to consider for further development that have been discussed in this report. The overall mission of the project was however achieved and provided a good foundation for VCC to continue with when further developing the next generation steering wheel.

10.7 Recommendations

The project was ended at the point where the functions of the proposed final concept could be tested. The prototypes have shown that the final concept has the possibility to provide a one-piece assembly on the assembly line. The overall project in turn has shown the advantages both in respect of cost savings and increased quality. Since the project was carried out as a first stage in the development process of a new steering wheel, there were many uncertainties regarding the final design of the steering wheel. This is one of the factors that need to be considered when recommendations for future work are made.

The development of the steering wheel and steering column pivot has been focused on minimizing play and at the same time make a one-piece assembly possible. The tests made in the project shows that it is possible to have an angled screw and at the same time gain enough axial force to prevent play in the attachment.

Fitting and securing tests has been carried out for the flexible connector sub-concept. It can be seen that the function of the flexible connector work properly at least when they are not resident in their respective parts, the airbag module and the clockspring. The electrical properties have not been possible to test, due to time limits of this project. Recommendations to VCC are thus that:

- The electrical properties of the flexible connector have to be verified.
- Different tests have to be carried out such as, vibration tests, temperature tests, pulling tests and signal tests.
- The two parts of the flexible connector have to be integrated in their respective component so a blind-mating assembly test could be conducted on the steering wheel and steering column.

Due to the uncertainties in the flexible connector sub-concept it could be wise to investigate other possible solutions in parallel with the development of the flexible connector. The brainstorming session of this report has shown on many different possibilities of an electrical connection between the airbag module and the clockspring. The authors recommend VCC to investigate the possibility of those sub-concepts as alternatives to the chosen final concept.

The proposed clockspring unlocking device in the final concept is a very simple and well known solution. The solution exists on the market already and many suppliers deliver this kind of solution. The recommendation to VCC is to verify the possibility to have this kind of solution and what their suppliers can deliver. According to this report a solution like this fulfills the demands of an unlocking device for the clockspring.

The project showed that the current solution of the airbag module is the most preferred. It provides an easy and non-tool needed insertion. The pros and cons with a screwed on airbag as an alternative has been discussed, due to better securing and verification of airbag. The recommendation from the author is to continue to develop the current solution. With a one-piece assembly the problem with gap and flush related to the insertion of the airbag can be minimized. Assembling the steering wheel outside the car provides a better overview which means that the assembly can be examined from different angles. Assembling outside the car also provides the possibility to use fixtures for the mounting of the airbag module and thus provides more control of the assembly compared to the current solution where insertion is made in a more or less angled position by hand.

The result from tests of the final concept shows that the function of the different sub-concepts works. The recommendation is to start integrating the different solutions into a final system-concept. The project shows that it is fully possible to do this but verification must be made to establish it. With a prototype of the entire final concept, the following tests can be conducted and give valuable information on the robustness and benefits of the final concept:

- Assembly test for time measuring.
- Verify that the final concept minimizes risk of incorrect assembly.
- Vibration tests.
- Weather tests.
- Crash test to determine the mechanical properties of the angled screw.
- Crash test to deploy the airbag and confirm the function of the flexible connector.

Regarding the verification of the airbag to clockspring connection using the flexible connector, a method is proposed here for VCC. If the clockspring is moved from the SWM and instead becomes integrated with the rest of the steering wheel assembly, the connection between the airbag and clockspring can be verified at the pre-assembly station. When the assembly personnel have mounted the parts of the steering wheel together, including the clockspring on the backside of the steering wheel, the signal can be tested. In the same way as the SRS warning light functions when there is an airbag failure in a car, the same control signal can be used with a control unit tool to verify that the clockspring and airbag are connected properly. If the control unit is connected to the clockspring when the pre-assembly is done and it does not give a warning signal, the clockspring and airbag are connected properly. If the control unit does give a warning signal, the airbag and clockspring connection has to be controlled.

As a final recommendation for VCC the authors of this report urge VCC to implement the strategy of studying many alternative solutions when conducting product development projects. This is not always common practice in the industry since it is regarded as too time consuming. The authors however hope that VCC will recognize that utilizing this strategy has many advantages and that it does not need to be very costly. Hopefully this project has presented a good example of how product development theories can be implemented and the advantages they provide.

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APPENDIX

APPENDIX A. DFA ANALYSIS RESULT – CURRENT STEERING WHEEL

DFX report

	Assembly of Steering Wheel and Airbag inside the car	Issue:	
		Issued by:	
Product/part:	Steering Wheel with deco och switchpack		

	Need to assemble part	Gripping by hand	Reachability	Insertion	Tolerances	Holding assembled parts	Fastening method	Separate operations	Agg Score	Agg Score (%)	Time	Agg Time	Agg Time (%)
Steering Wheel with deco och switchpack									320	74%		50,4	280%
Clock spring och steering column	9	9	9	9	9	9	9	9			3		
Steering Wheel	9	9	3	9	3	3	3	3			10,7		
Locking screw	1	9	1	9	3	9	3	9			13,2		
Cabels from switchpack	9	9	3	3	3	9	9	9			7,9		
Cabels for Airbag	9	3	3	3	3	9	9	9			7,9		
Airbag	9	9	3	3	9	9	9	9			7,7		

DFX report

	Preassembly of steering wheel	Issue:	
		Issued by:	
Product/part:	Steering Wheel without deco and switchpack		

	Need to assemble part	Gripping by hand	Reachability	Insertion	Tolerances	Holding assembled parts	Fastening method	Separate operations	Agg Score	Agg Score (%)	Time	Agg Time	Agg Time (%)
Steering Wheel without deco and switchpack									258	72%		37,6	251%
Steering wheel	9	9	9	9	9	9	9	9			3		
Cabels for switchpack and horn	9	3	9	3	3	3	3	9			6,4		
Switchpack left	9	9	3	9	1	3	3	9			10,9		
Switchpack right	9	9	3	9	1	3	3	9			10,9		
Deco	9	9	9	9	1	3	3	9			6,4		

APPENDIX B. INTERVIEW STATEMENTS AND INTERPRETED NEEDS

Assembly line workers		
Question/Topic	**Interview Statement**	**Interpreted Need**
- Working procedures and sequence comments	Good to have many steps per car, long work cycle	It is possible for one person to carry out all the steps alone.
	A lot of detail work, takes a long time to learn how to do fast. Small details and small spaces are troublesome.	The placement of interfacing parts are done in such a way that it is easy to reach in small spaces
	Depending in which order the cars come in, the time to assemble varies because the cars are different and this can be stressful	Homogenous assembly method for all steering wheels.
	The nut is fastened to the steering wheel column loosely first, then after the clockspring is released the nut is fastened tightly, this allows the sequence to only be done in a specific order	The securing nut can be fastened whenever the steering wheel is on the steering column, independent of other parts state.
	Sometimes the worker needs to wait for the car to reach a certain point, in order to continue with the assembly. During the waiting the worker does nothing. Especially between releasing of the clockspring screw and fastening of the center screw.	All the steps in the process are able to complete in full sequence without waiting.
- Dysfunctional design or construction issues	Design engineering department have stated that it is impossible to insert the airbag incorrectly, however there have been cases where the airbag is skewed.	It is impossible to assemble the airbag incorrectly. Either it’s done right, or not at all.

	We press three critical control points on the airbag after assembly to see that it is flexing and at the same time is stuck to the wheel correctly. No definite feedback except for trying with your hands.	It is possible to test the fitting of the airbag at assembly station in an easy way.
	Some workers assemble the airbag with only one hand	It is impossible to assemble the airbag incorrectly. Either it’s done right, or not at all.
	Wooden wheel have a harder material and the deco parts are difficult to put in. this is also true when working in lower temperatures and you assemble a leather wheel.	Assembly effort is not affected by differences in material and part variants
- Reachability and visibility and feedback	Much easier to assembly outside the car, in terms of visibility and accessibility	All steps, except fastening, securing fixating the steering wheel on the steering column is done outside the car.
	Disassemble the screw from clockspring takes approx. 648 TMU (24 sec).	Release the clockspring should take less the 24 sec
	Personnel push in the airbag when the steering wheel is in the car, this gives a troubling angle of pressure and results in gap disturbance.	Airbag is assembled to the steering wheel with a force normal to the steering wheel rim.

Manufacturing engineers		
Question/Topic	**Interview Statement**	**Interpreted Need**
- Quality related comments	Foam can go back to original shape if it has been deformed	Foam can go back to original shape if it has been deformed
	The mounting screw for the steering wheel column is used as a quality assurance	Some feedback is needed to secure quality
	The airbag is currently controlled by two different independent persons on different places on the line to secure that it is assembled correctly	The airbag fitting needs to be checked at the assembly station
	The assembly of the steering wheel takes in total 3583 TMU (2:12 min)	The steering wheel will have a maximum assembly time of 3583 TMU (2:12 min)
	The assembly of the steering wheel in the car takes in total 2363 TMU (1:27 min)	The assembly inside the car should have a maximum assembly time of 2363 TMU
	Foam contributes to a lot of problems, especially with sharp edges which cut the foam and creates a mismatching	If foam is used no sharp edges can be used which can damage the foam
	4 cylinder motor reduce the vibrations from the motor and the damping device is maybe not needed	4 cylinder motor reduce the vibrations from the motor
- Feasibility	To ensure the quality and to make it easier to assemble chamfer and guiding pins are good to use	Chamfers and guiding pins make it easier to assemble and makes it harder to do anything wrong
	The two latches hits the airbag before the three guiding feet aligns in the guiding holes	The guiding pins/holes must be the first points to align before the fastener
- Efficiency	It is better to do assembly away from the line	Reduce the number of mounting steps on the line

Clockspring (SWM)		
Question/Topic	**Interview Statement**	**Interpreted Need**
- Locking the clockspring when not assembled	The locking screw used today is a cheap solution, and has always been there	A cheap solution is needed for locking the clockspring
	Competitors uses other solutions such as spring loaded sprint	The clockspring should be able to lock with any solution
	Sometimes assembly workers forget to release the screw which results in a locked steering wheel	A “fool proof” solution is preferred
	Supplier can see which revolution the clockspring is on, but assembly personnel cannot, they rely on the supplier that it is correctly calibrated to middle point.	Sometimes it can be preferred to have a clearer indication if the clockspring is in the middle state
- Special requirements	The Airbag connectors must be gold plated for best connector	The best conductivity is needed in the connector
	SRS demand that as few transitions as possible be made between airbag and SRS unit.	SRS demand that as few transitions as possible be made between airbag and SRS unit.
	Cables require to be welded to the clockspring connector for best quality	Cables require to be welded to the clockspring connector for best quality
	The angle sensor reads from the clockspring	The angle sensor reads from the clockspring
- Critical functions that needs to be saved	The clockspring must include the rolled cable	The rolled cable is a requirement
	The clockspring have special connectors for airbag	The clockspring have special connectors for airbag
	The cables connectors should have modules for future additions	Space for extra connectors is needed.

Design		
Question/Topic	**Interview Statement**	**Interpreted Need**
- Quality	A premium brand as Volvo has a floating airbag	Airbag must be movable in all direction
	The steering wheel is made up of modules to give customer personal options, this requires many variants	New design should enable many variants with as few parts as possible
	Damping is needed to prevent rattling noises traveling from the steering column	The steering wheel has to be damped
	The gap and flush variation needs to be stable	The assembly of the steering wheel needs to be robust against variation in material, dimensions and positions
	Extra connectors are needed between airbag and clockspring, to secure the functionality of the damping device.	The design will not allow the cables to disturbed the function of the damping device.
- Electrical	Must be sure that ground is connected to the airbag	No doubts that ground is connected to the airbag
	The connector to the SRS sensor must be a short circuit connector	The connector to the SRS sensor must be a short circuit connector
- Mechanical	The extra connector requires a mounting plate which increases cost	It is desirable to reduce this mounting plate.
	The damping device inside the airbag can malfunction from cables	Control over the cables is necessary
	A change in the design has been made to prevent the airbag feet's to cut the foam	Airbag needs to be guided to the right position without destroying the foam
	The centre screw is held in place by the airbag if the screw unintentionally gets loose. This is to prevent the steering wheel from falling of if the screw is loose.	If the screw loosens, the steering wheel must stay in place and not come off.

Appendix C. House of Quality

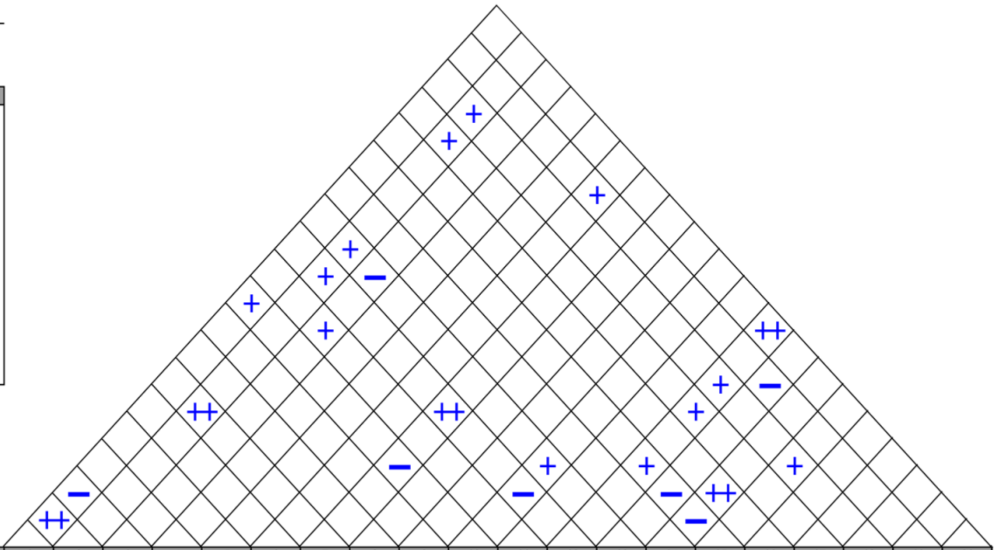
Title: House of quality Steering wheel - Airbag assembly

Author: Alex Dramountanis & Henrik Karlsson

Date: 2010-01-26

Notes:

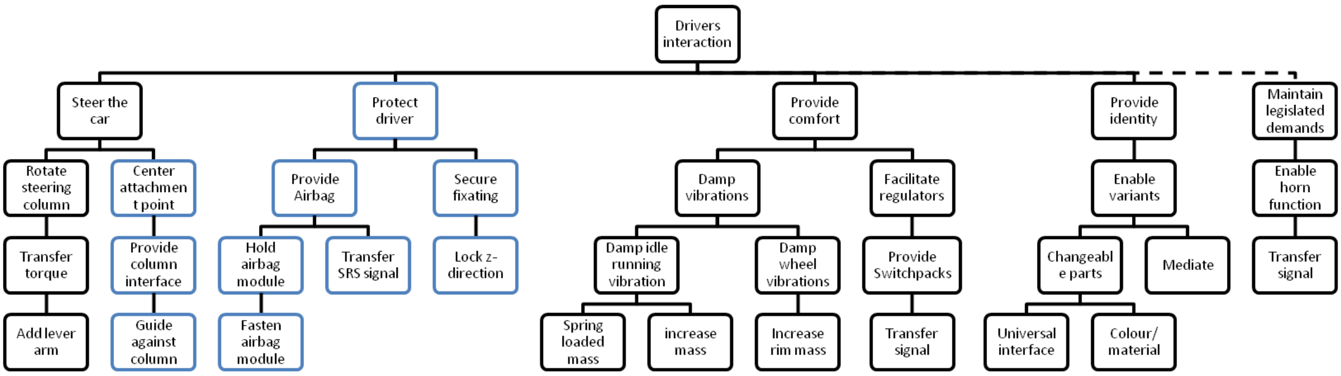
Legend		
Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼ (blue)	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	



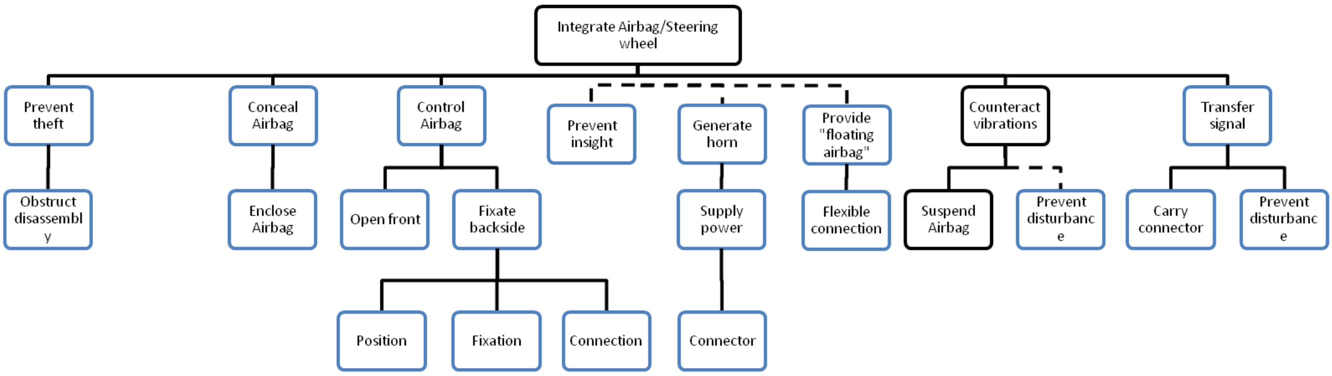
Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Column # / Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	1 signal input/output variation	2 Number of connectors in circuit(#)	3 input current to steering wheel(A)	4 pulling force normal to the steering wheel(N)	5 Torque(Nm)	6 steering column vibration(Hz)	7 manual connecting operations(haptic)	8 number of audio signals for feedback per operation	9 sound level of audio feedback	10 length of cable slack	11 evaluation score of functionality	12 assembly time	13 material cost	14 manufacturing cost	15 number of guiding elements	16 ratio between variants and parts (variants/parts)	17 ratio between current number of steps and new number of steps in assembly	18 DFA Score	19 total weight	20 number of assembly operations outside the line
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)	▼	▼	x	x	x	▼	▼	x	▲	▼	▲	▼	▼	▼	▲	▲	▲	▲	▼	▲
1	9	12,9	4,0	The electrical circuit connecting the airbag to SRS unit must be resistant to disturbances	Θ	Θ	O			▲														
2	9	12,9	4,0	the fastening and securing of the steering wheel to the steering column is a crucial safety issue				Θ	O	O													▲	▲
3	3	9,7	3,0	feedback is needed to ensure build quality							O	O	O											
4	9	9,7	3,0	moving parts within the steering wheel assembly needs to be controlled so that they don't interefer							▲			Θ										
5	9	9,7	3,0	regardless of any design changes to the steering wheel, functions should be maintained											Θ									
6	9	9,7	3,0	the new design needs to reduce overall costs and/or assembly time												Θ	O	Θ		▲			▲	
7	9	9,7	3,0	it should be easy to determine if the assembly has been done correctly or not							Θ	O	▲						Θ					
8	9	6,5	2,0	guiding features are needed for fast, easy and correct assembly							▲			O					Θ					
9	9	6,5	2,0	the design needs to be adapted to be compatible with future additions to the steering wheel		▲	O													Θ				
10	9	6,5	2,0	new design needs to reduce the number of assembly steps made on the line							O					Θ				▲	Θ	Θ		Θ
11	9	3,2	1,0	the ergonomic aspects of the assembly needs to be taken into consideration							▲			O		▲			O			O	Θ	Θ
12	1	3,2	1,0	one person alone should be able to assemble the steering wheel in one complete cycle												▲					▲			▲
				Target or Limit Value																				
				Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)																				
				Max Relationship Value in Column	9	9	3	9	3	3	9	3	3	9	9	9	3	9	9	9	9	9	9	9
				Weight / Importance	116,1	122,6	58,1	116,1	38,7	51,6	154,8	58,1	38,7	116,1	87,1	151,6	29,0	87,1	154,8	74,2	61,3	67,7	51,6	103,2
				Relative Weight	6,7	7,1	3,3	6,7	2,2	3,0	8,9	3,3	2,2	6,7	5,0	8,7	1,7	5,0	8,9	4,3	3,5	3,9	3,0	5,9

APPENDIX D: FUNCTION ANALYSIS TREES FOR THE STEERING WHEEL ASSEMBLY

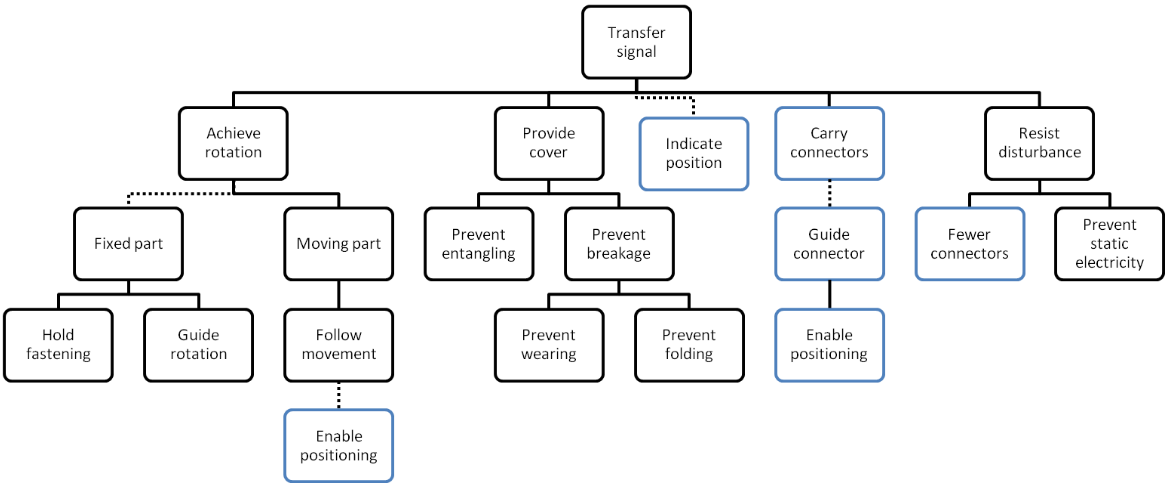
STEERING WHEEL FUNCTION ANALYSIS TREE



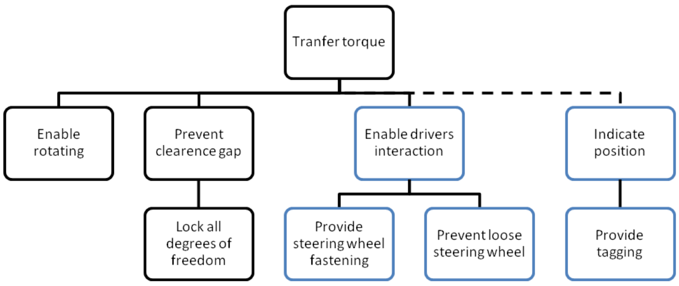
AIRBAG MODULE FUNCTION ANALYSIS TREE



CLOCKSPRING FUNCTION ANALYSIS TREE



STEERING COLUMN FUNCTION ANALYSIS TREE



Appendix E. Brainstorm concepts

GENERAL IDEAS FOR HOW THE STEERING WHEEL COULD BE ASSEMBLED

- The steering wheel consists of the same parts as today and are mounted as it is today, but changes in the interfaces are made
- steering wheel consist of the same parts as today but are mounted outside the line
- The deco also carries the cover for the airbag
    - The cover is spring loaded for the horn
    - The cover has a built-in button for the horn
- The steering wheel has a back cover and the magnesium is minimized
- clockspring is mounted on the steering wheel

IDEAS REGARDING WHEN AND HOW TO RELEASE THE CLOCKSPRING

- Released only when airbag is mounted
- Connected to securing of steering wheel to steering column
- When the steering wheel and clockspring comes in contact with each other, the clockspring is released
- No locking device, sealed when it arrives at Volvo Car Corporation and does not need to be relocked.

IDEAS REGARDING HOW TO CONNECT AIRBAG TO THE CLOCKSPRING WITHOUT DISRUPTING THE VIBRATION DAMPING

- Guided cable
    - Backward facing connector on airbag module with pre-defined cable slack. Slack is then drawn to the backside of the steering wheel
    - Cables from clockspring and guided through a pocket for constraining of cable slack
        - No connector on rotating part of clockspring. clockspring cable goes through rotating part and into steering wheel (straight through clockspring cable)
- Airbag connector is going through the steering wheel and connected to clockspring with cable
- Flexible connector
    - Spring loaded connector with "feet"
    - Spring loaded connector with funnel guiding element
    - Rubber membrane (fastening clips)
    - Spider connector
    - Rotating hooks with upward facing force
    - Connector with guiding pin and wedge, releases when airbag is mounted
- Board protecting the damping device and thicker cable prevents pinching
- Guide pins

IDEAS REGARDING THE MOUNTING OF THE AIRBAG MODULE

- The deco also carries the cover for the airbag
    - The cover is spring loaded for the horn
        - Airbag and clockspring is mounted through the steering wheel
        - The airbag has a snap-on function
        - The airbag is screwed from the front or back
    - Airbag covers the hole to the clockspring
        - The connection can be done with hands
        - Switch packs and heat connects to airbag module and airbag module carries the connector to clockspring

- The airbag is screwed into place
- Same latches as today but spring loaded without sleeve coupling
- Fastening and securing the airbag on the steering column and guide it in the steering wheel
    - Aperture locking device (camera shutter clips)
    - Screw
- Prevent thievery
    - Electronically match the airbag with the car somehow, Code, Color, Asymmetric lock etc
    - Solenoid released from service computer when key located in the slot
- Slide the airbag from above into slot

IDEAS REGARDING HOW TO LOCK THE CLOCKSPRING

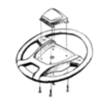
- Screw
- Spring loaded
    - Mechanism in middle of clockspring
    - Midsection is spring loaded, front and backside can move relative to each other
    - Pin in hole to release
- Releasing mechanism under airbag module feet, works as feedback for correct airbag mounting
- Hand released sprint
- No locking device, indication
    - Rotating gear with indicator
    - Breakable sealing and indication
- Key hole
- Magnet
- Push button
- Gear lock
- Friction

IDEAS REGARDING THE FASTENING AND SECURING OF THE STEERING WHEEL

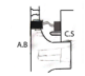
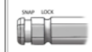
- Clips
    - Bow clips
    - Straight clips
- Spring loaded pin
- Cross screw/pin trough steering pivot
- Touching pin
- Top locking screw/pin
- Spring loaded balls
- Press fit
- Wedge
- Spiral screw (IKEA)
- Corkscrew (grooved pivot)
- Vice
- T-screw
- Hose clamp
- Touching pin with clip
- Threaded steering wheel and pivot

APPENDIX F. PUGH AND KESSELRING MATRICES FOR SUB-CONCEPTS

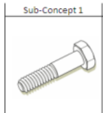
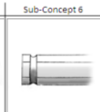
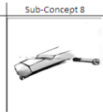
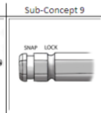
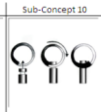
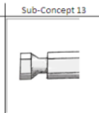
Airbag mounting

	Pugh Matrix	Current sub-solution	Sub-Concept 1	Sub-Concept 2	Sub-Concept 3	Sub-Concept 4	Sub-Concept5	Sub-Concept 6
								
		Current solution	The airbag is screwed from front	The airbag is screwed from back	Latches and springs	Aperture locking on steering col.	AB and CS mounted through SW	Slide the airbag from above
New design reduces assembly time	Short Assembly time	0	-	-	0	-	-	0
	No additional tools needed	0	-	-	0	0	0	0
	Simplifies assembly operations	0	-	-	0	0	-	-
	few separate operations needed	0	-	-	0	-	0	0
Feedback and verification to ensure build quality	Resistance to human errors (memory)	0	+	+	0	0	0	0
	Good Feedback to assembly personnel	0	+	+	0	0	0	0
	minimizes risks for gap and/or flush	0	+	+	0	0	+	+
	Able to verify mounting	0	+	+	0	0	0	0
New design reduces overall cost	Low Number of parts	0	-	0	0	-	0	-
	Manufacturable	0	0	0	+	-	-	-
	Lower Cost	0	0	0	+	-	-	-
Guiding features for fast, easy and correct assembly	Good guidance for airbag	0	+	+	0	0	0	+
	Provides possibility for more ergonomic ass.	0	+	+	0	-	+	+
Theft protection	Easier to assemble than disassemble	0	0	+	+	0	+	0
	sum +	0	6	7	3	0	3	3
	sum -	0	5	4	0	6	4	4
	sum 0	14	3	3	11	5	7	7
	Total score	0	1	3	3	-6	-1	-1
	Rank	**3**	**2**	**1**	**1**	**5**	**4**	**4**

Airbag to SWM Connection

		Sub-Concept 1	Sub-Concept 2	Sub-Concept 3	Sub-Concept 4	Sub-Concept 5	Sub-Concept 6	Sub-Concept 7	Sub-Concept 8	Sub-Concept 9	Sub-Concept 10	Sub-Concept 11	Sub-Concept 12	Sub-Concept 13	Sub-Concept 14	Sub-Concept 15	Sub-Concept 16
																	
	Pugh Matrix	Current	back-facing connector to SWM	slack-pocket	straight-through -CS cable	flexible connector	board and fat cable	Cable clips next to bag	AB to CS through SW	snap-lock	Ikea screw	tightening balls	press fit	wedge	vice (skruvstäd)	T-screw	threaded steering wheel and column
The SRS signal to airbag must be resistant to distrubances	few connectors	0	0	+	+	+	+	+	+	0	0	0	-	0	0	0	0
	low risk of connector gnuggning	0	0	0	0	0	0	0	0	0	0	-	0	0	-	-	0
										0	0	+	0	0	0	0	-
New design reduces assembly time	Short Assembly time	0	0	-	0	+	0	0	+								
	No additional tools needed	0	0	0	0	0	0	0	0								
	Simplifies assembly operations	0	0	0	0	+	0	0	+	0	0	-	-	0	0	-	-
	Does not require separate operation	0	0	-	0	0	0	-	0	0	0	0	-	0	0	0	-
										-	-	-	-	-	-	-	-
Feedback to ensure build quality	Resistance to human errors (memory)	0	0	0	0	+	0	0	+	0	0	-	-	0	0	-	-
	Good Feedback to assembly personnel	0	0	0	0	-	0	0	-								
										0	0	-	-	0	0	0	0
New design reduces overall cost	Low Number of parts	0	+	+	+	+	+	+	+	+	0	0	-	0	0	0	0
	Manufacturable	0	0	0	0	-	0	0	-								
	Lower Cost	0	+	+	0	0	+	+	-								
										-	0	-	+	0	-	-	+
Guiding features for fast, easy and correct assembly	low risk for vibration damping interferance	0	0	-	0	0	-	-	0	-	-	-	+	-	-	-	-
	Good visibility	0	0	-	0	-	0	0	-	-	-	-	-	-	-	-	-
	good guidance for loose parts (cables)	0	+	0	0	+	0	0	+								
	Provides possibility for more ergonomic ass.	0	+	+	+	+	0	+	+	0	0	0	0	0	0	0	0
										0	0	0	0	0	0	0	-
	sum +	0	4	4	3	7	3	4	7								
	sum -	0	0	4	0	3	1	2	4	+	-	-	+	-	-	0	-
	sum 0	15	11	7	12	5	11	9	4								
	Total score	**0**	**4**	**0**	**3**	**4**	**2**	**2**	**3**	2	0	1	3	0	0	0	1
	Rank	4	1	4	2	1	3	3	2	4	4	9	8	4	6	7	9
	sum 0	15	8	4	3	11	12	12	10	9	11	5	4	11	9	8	5
	Total score	**0**	**-3**	**1**	**0**	**-2**	**-3**	**-3**	**-3**	**-2**	**-4**	**-8**	**-5**	**-4**	**-6**	**-7**	**-8**
	Rank	**2**	**4**	**1**	**2**	**3**	**4**	**4**	**4**	**3**	**5**	**9**	**6**	**5**	**7**	**8**	**9**

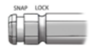
Steering Wheel Securing

		Sub-Concept 1	Sub-Concept 2	Sub-Concept 3	Sub-Concept 4	Sub-Concept5	Sub-Concept 6	Sub-Concept 7	Sub-Concept 8	Sub-Concept 9	Sub-Concept 10	Sub-Concept 11	Sub-Concept 12	Sub-Concept 13	Sub-Concept 14	Sub-Concept 1
																
	Pugh Matrix	straight on screw	curved clips with tighting screw	Straight clips	Spring loaded pin	Screw through ass. steering column	Touching screw	Top locking screw	tight angle screw on ass. Col.	snap-lock	Ikea screw	tightening balls	press fit	wedge	vice (skruvstäd)	T-screw
Fastening and securing the steering wheel is crucial to driver safety	Able to verify mounting	0	0	-	-	0	0	0	0	0	0	0	-	0	0	0
	Low risk of play in z-direction	0	-	-	-	-	-	-	0	0	0	-	0	0	-	-
	Handles steering torque	0	0	0	0	0	0	0	0	0	0	+	0	0	0	0
New design reduces assembly time	Short Assembly time	0	0	+	+	0	0	0	0	0	0	-	-	0	0	-
	No additional tools needed	0	0	+	+	0	0	0	0	0	0	0	-	0	0	0
	Simplifies assembly operations	0	-	+	+	-	-	-	-	-	-	-	-	-	-	-
	Does not require separate operation	0	0	+	+	0	0	0	0	0	0	-	-	0	0	-
Feedback to ensure build quality	Resistance to human errors	0	0	+	+	0	0	0	0	0	0	-	-	0	0	0
	Good Feedback to assembly personnel	0	+	+	+	0	0	0	0	+	0	0	-	0	0	0
New design reduces overall cost	Low Number of parts	0	-	0	-	0	0	0	0	-	0	-	+	0	-	-
	Manufacturable	0	-	-	-	0	0	0	-	-	-	-	+	-	-	-
	Lower Cost	0	-	-	-	0	0	0	-	-	-	-	-	-	-	-
Guiding features for fast, easy and correct assembly	Good guidance for steering wheel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Easy to position correctly ref. to wheels	0	0	0	0	+	0	0	+	0	0	0	0	0	0	0
Theft protection	Easier to assemable than disassemble	0	+	-	-	-	-	-	-	+	-	-	+	-	-	0
	sum +	0	2	6	6	1	0	0	1	2	0	1	3	0	0	0
	sum -	0	5	5	6	3	3	3	4	4	4	9	8	4	6	7
	sum 0	15	8	4	3	11	12	12	10	9	11	5	4	11	9	8
	Total score	**0**	**-3**	**1**	**0**	**-2**	**-3**	**-3**	**-3**	**-2**	**-4**	**-8**	**-5**	**-4**	**-6**	**-7**
	Rank	**2**	**4**	**1**	**2**	**3**	**4**	**4**	**4**	**3**	**5**	**9**	**6**	**5**	**7**	**8**

Steering Wheel Securing

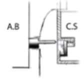
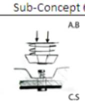
Kesselring Matrix

	Criterion	Weight	Sub-Concept 1  straight on screw		Sub-Concept 2 curved clips with tighting screw		Sub-Concept 3 Straight clips		Sub-Concept 4 Spring loaded pin		Sub-Concept5  Screw through ass. steering column	
Fastening and securing the steering wheel is crucial to driver safety	Able to verify mounting	**10**	5	50	4	40	1	10	1	10	5	50
	Low risk of play in z-direction	**10**	5	50	3	30	2	20	3	30	3	30
	Handles steering torque	**8**	5	40	5	40	5	40	5	40	5	40
				0		0		0		0		0
				0		0		0		0		0
New design reduces assembly time	Short Assembly time	**6**	2	12	2	12	5	30	5	30	2	12
	No additional tools needed	**7**	2	14	2	14	5	35	5	35	2	14
	Simplifies assembly operations	**5**	3	15	2	10	5	25	5	25	3	15
	Does not require separate operation	**5**	2	10	4	20	5	25	5	25	2	10
				0		0		0		0		0
Feedback to ensure build quality	Resistance to human errors	**5**	4	20	3	15	3	15	3	15	4	20
	Good Feedback to assembly personnel	**8**	4	32	5	40	4	32	4	32	4	32
				0		0		0		0		0
				0		0		0		0		0
New design reduces overall cost	Low Number of parts	**2**	5	10	3	6	4	8	4	8	5	10
	Manufacturable	**5**	5	25	2	10	4	20	3	15	4	20
	Lower Cost	**3**	5	15	2	6	4	12	3	9	4	12
				0		0		0		0		0
Guiding features for fast, easy and correct assembly	Good guidance for steering wheel	**6**	4	24	4	24	4	24	4	24	5	30
	Easy to position correctly ref. to wheels	**7**	3	21	3	21	3	21	3	21	5	35
				0		0		0		0		0
Theft protection	Easier to assemable than disassemble	**4**	3	12	4	16	3	12	3	12	3	12
				0		0		0		0		0
	Total score			350		304		329		331		342
	Rank		**ref**			**9**		**7**		**6**		**2**

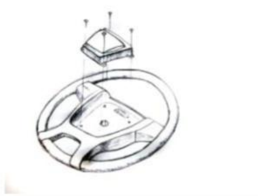
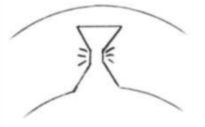
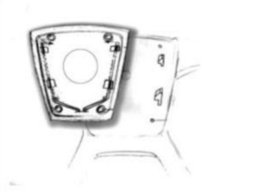
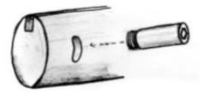
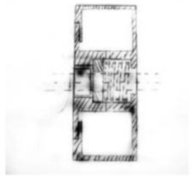
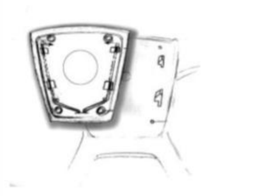
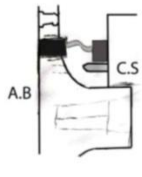
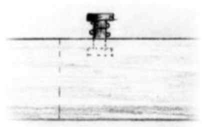
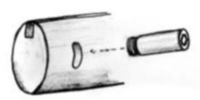
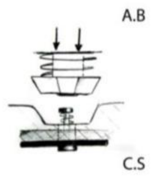
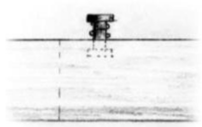
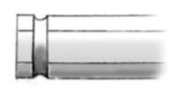
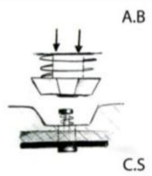
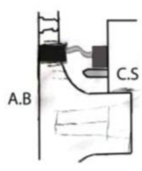
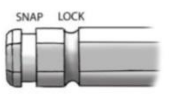
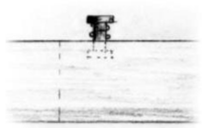
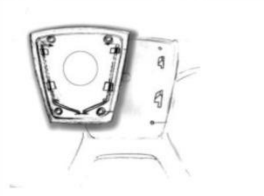
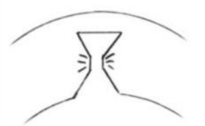
	Criterion	Weight	Sub-Concept 6  Touching screw		Sub-Concept 7 Top locking screw		Sub-Concept 8  tight angle screw on ass. Col.		Sub-Concept 9  snap-lock		Sub-Concept 10 Ikea screw		Sub-Concept 13 wedge	
Fastening and securing the steering wheel is crucial to driver safety	Able to verify mounting	**10**	5	50	5	50	5	50	5	50	5	50	5	50
	Low risk of play in z-direction	**10**	4	40	2	20	5	50	4	40	4	40	4	40
	Handles steering torque	**8**	5	40	5	40	5	40	5	40	5	40	5	40
				0		0		0		0		0		0
				0		0		0		0		0		0
New design reduces assembly time	Short Assembly time	**6**	2	12	2	12	2	12	2	12	3	18	2	12
	No additional tools needed	**7**	2	14	2	14	2	14	2	14	2	14	2	14
	Simplifies assembly operations	**5**	3	15	3	15	3	15	3	15	3	15	3	15
	Does not require separate operation	**5**	2	10	4	20	2	10	3	15	5	25	3	15
				0		0		0		0		0		0
Feedback to ensure build quality	Resistance to human errors	**5**	4	20	4	20	4	20	3	15	4	20	4	20
	Good Feedback to assembly personnel	**8**	4	32	4	32	4	32	5	40	4	32	4	32
				0		0		0		0		0		0
				0		0		0		0		0		0
New design reduces overall cost	Low Number of parts	**2**	5	10	5	10	5	10	3	6	5	10	5	10
	Manufacturable	**5**	4	20	4	20	3	15	3	15	2	10	3	15
	Lower Cost	**3**	4	12	4	12	4	12	4	12	3	9	4	12
				0		0		0		0		0		0
Guiding features for fast, easy and correct assembly	Good guidance for steering wheel	**6**	4	24	4	24	5	30	4	24	4	24	4	24
	Easy to position correctly ref. to wheels	**7**	3	21	3	21	5	35	3	21	3	21	3	21
				0		0		0		0		0		0
Theft protection	Easier to assemable than disassemble	**4**	3	12	3	12	3	12	4	16	2	8	3	12
				0		0		0		0		0		0
	Total score			332		322		357		335		336		332
	Rank			**5**		**8**		**1**		**4**		**3**		**5**

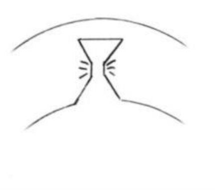
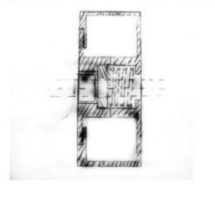
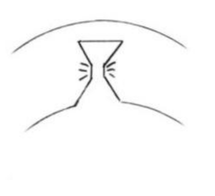
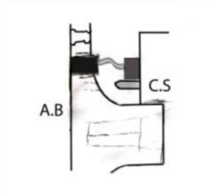
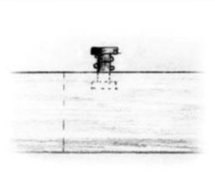
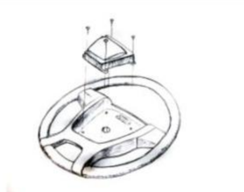
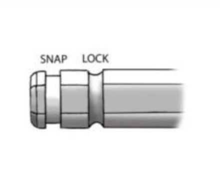
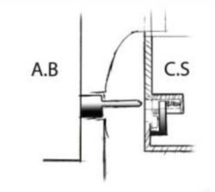
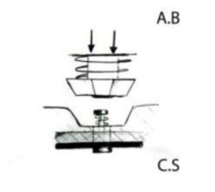
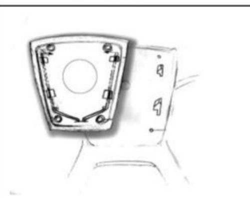
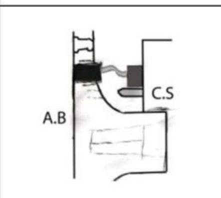
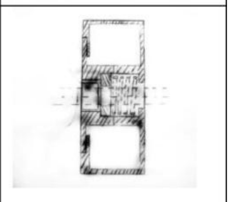
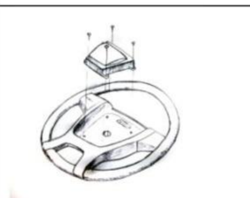
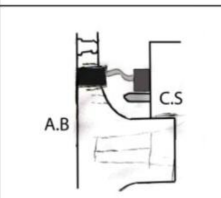
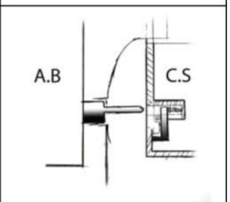
Clockspring locking

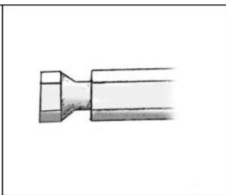
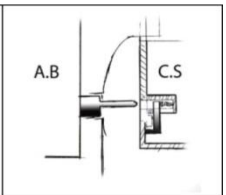
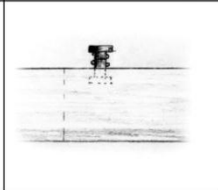
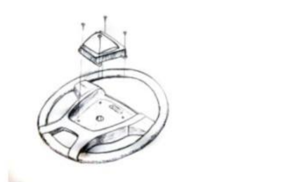
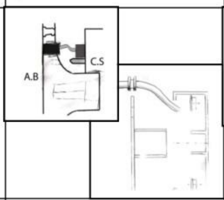
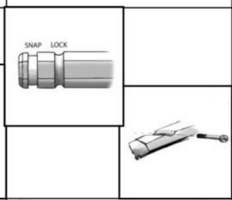
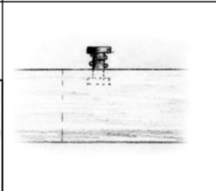
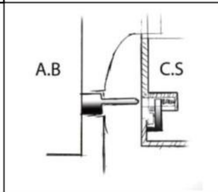
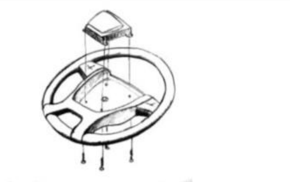
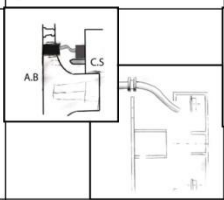
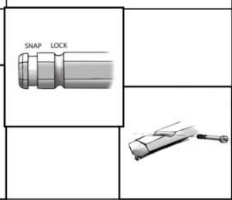
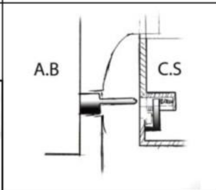
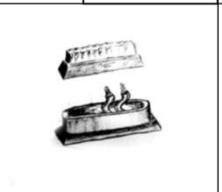
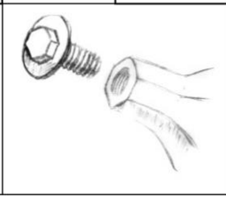
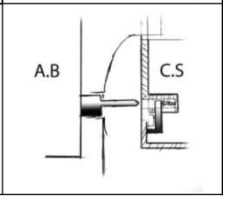
Pugh Matrix

		Sub-Concept 1	Sub-Concept 2	Sub-Concept 3	Sub-Concept 4	Sub-Concept 5	Sub-Concept 6	Sub-Concept 7	Sub-Concept 8	Sub-Concept 9
										
	Pugh Matrix	Screw	Spring in center of clockspring	midsection is spring loaded	pin in hole unlock	press pin to unlock	DAB feet unlocks CS(springload)	Manually removed sprint unlocks CS	no locking device	Breakable sealing (one time locking)
The locking function of the clockspring	Easy to relock	0	+	+	+	+	0	0	-	-
	Easy to unlock	0	+	+	+	+	+	+	+	+
	Cannot be accidently unlocked	0	0	-	+	-	+	0	-	-
	Able to lock in multiple positions	0	0	0	0	0	0	0	-	-
New design reduces assembly time	Short Assembly time	0	+	+	+	+	+	+	+	+
	No additional tools needed	0	+	+	+	+	+	+	+	+
	Simplifies assembly operations	0	+	+	+	+	+	+	-	+
	Does not require separate operation	0	+	+	+	+	+	0	-	+
Feedback to ensure build quality	Resistance to human errors (memory)	0	+	+	+	+	+	0	+	+
	Good Feedback to assembly personnel	0	0	0	0	0	+	0	0	0
	The concept is robust	0	+	+	+	+	+	0	-	+
New design reduces overall cost	Low Number of parts	0	-	0	0	0	-	0	+	+
	Manufacturable	0	0	-	0	0	-	0	+	+
	Lower Cost	0	-	-	-	-	-	0	+	+
	sum +	0	8	8	9	8	9	4	7	10
	sum -	0	2	3	1	2	3	0	6	3
	sum 0	14	4	3	4	4	2	10	1	1
	Total score	**0**	**6**	**5**	**8**	**6**	**6**	**4**	**1**	**7**
	Rank	**7**	**3**	**4**	**1**	**3**	**3**	**5**	**6**	**2**

APPENDIX G. MORPHOLOGICAL MATRIX RESULT LIST

	Airbag mounting	**Airbag to SWM connection**	**Steering wheel securing**	**Clock spring locking**
System-Concept 1				
System-Concept 2				
System-Concept 3				
System-Concept 4				
System-Concept 5				
System-Concept 6				
System-Concept 7				
System-Concept 8				

System-Concept 9				
System-Concept 10				
System-Concept 11				
System-Concept 12				
System-Concept 13				
System-Concept 14				
System-Concept 15				
System-Concept 16				

System-Concept 17				
System-Concept 18				
System-Concept 19				
System-Concept 20				
System-Concept21				
System-Concept 22				

APPENDIX H. MORPHOLOGICAL MATRIX PUGH AND KESSELRING MATRICES

The system-concepts marked with blue are the winning concepts. The red ones were not taken for further development. System-concept 1421 and the final concept were added in a later state than the others and have been marked yellow and green respectively to distinguish them from the rest.

Pugh Matrix of system-concepts from morphological matrix

		System-Concept 1	System-Concept 2	System-Concept 3	System-Concept 4	System-Concept 5	System-Concept 6	System-Concept 7	System-Concept 8	System-Concept 9	System-Concept 10	System-Concept 11	System-Concept 12	System-Concept 13	System-Concept 14	System-Concept 15	System-Concept 16	System-Concept 17	System-Concept 18	System-Concept 19	System-Concept 20	System-Concept 21	System-Concept 22	System-Concept 1421	Final Concept
The SRS signal to airbag must be resistant to distrubances	few connectors	0	-	-	-	0	-	-	0	-	0	0	-	-	0	-	-	0	0	0	0	0	0	0	0
	low risk of connector gnuggning	0	-	0	-	0	-	0	-	-	+	-	0	0	+	-	0	+	+	0	+	0	+	+	+
Fastening and securing the steering wheel is crucial to driver safety	Able to verify mounting steering wheel	0	+	+	+	+	+	0	0	+	0	0	+	+	+	+	0	+	+	+	+	+	+	+	+
	Low risk of play in z-direction	0	-	-	-	+	-	0	0	-	0	0	-	0	+	+	0	+	+	+	+	+	+	+	+
	Handles steering torque	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Able to verify mounting Airbag	0	-	-	0	0	0	0	-	-	-	-	0	0	-	-	0	-	-	0	-	0	-	-	-
Feedback to ensure build quality	Resistance to human errors (not easy to forget)	0	+	+	+	0	+	+	+	+	+	+	+	0	+	+	0	+	+	+	+	0	+	+	+
	Good Feedback to assembly personnel (sound vision)	0	+	+	+	+	+	+	0	0	0	0	0	0	+	+	0	+	+	+	+	+	+	+	+
New design reduces assembly time	Short Assembly time	0	+	+	+	0	+	0	+	+	+	+	0	0	+	+	0	+	+	0	+	0	+	+	+
	No additional tools needed	0	+	+	+	+	+	0	+	+	+	+	+	0	+	+	0	+	+	+	+	+	+	+	+
	Simplifies assembly operations	0	+	+	+	-	+	-	+	+	+	+	+	0	+	+	0	+	+	0	+	+	+	+	+
The locking function of the clockspring	Easy to unlock	0	+	+	+	+	+	+	0	0	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+
	Easy to relock	0	+	+	+	+	+	+	0	0	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+
	Cannot be accidently unlocked	0	0	-	+	-	+	-	0	0	+	0	-	+	+	+	+	+	-	-	+	+	+	+	-
	Able to lock in multiple positions	0	+	+	+	+	+	+	0	0	+	0	+	+	+	+	+	+	+	+	+	+	+	+	+
Moving parts must not interfere with any functions	Good guidance for loose parts (cables)	0	-	-	0	0	0	0	-	-	+	-	0	0	+	-	0	+	+	0	+	0	+	+	+
New design reduces overall cost	Low Number of parts	0	-	-	-	-	-	-	0	-	-	0	0	-	-	-	-	-	-	-	-	-	-	-	-
	Manufacturable	0	-	+	0	0	0	0	-	-	-	-	0	-	-	0	0	-	-	0	-	0	-	-	-
	Lower Cost	0	-	0	-	0	0	0	-	0	-	-	0	-	-	0	-	-	-	0	-	-	-	-	-
Guiding features for fast, easy and correct assembly	Low risk of vibration damping interferance	0	0	0	0	0	0	0	-	-	0	-	0	0	0	-	0	0	0	0	0	0	0	0	0
	Good visibility of assembly	0	-	-	-	0	-	0	-	-	-	-	0	0	-	-	0	-	-	0	-	0	0	-	-
	Provides possibility for more ergonomic assembly	0	+	+	-	-	-	-	+	+	+	+	0	0	-	0	0	0	0	0	0	0	-	0	0
	Many guiding features	0	+	+	+	+	0	0	0	0	0	0	+	+	+	+	0	0	+	+	+	+	+	+	+
The design needs to be compatible with future additions to the SW	supports modularity and platform thinking	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Provides support for different sequences of assembly	0	0	0	-	-	-	-	0	0	0	0	0	0	-	0	0	0	0	0	0	0	-	0	0
One person alone should be able to assemble to complete SW	Criteria: Weight, reach, visibility, complexity of assembly	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Theft protection	Easier to assemable than disassemble	0	+	+	+	+	+	+	+	+	+	+	0	+	+	+	0	+	+	+	+	+	+	+	+
	sum +	0	12	13	12	9	11	6	6	7	12	6	8	7	15	13	4	14	14	10	15	11	15	15	14
	sum -	0	9	7	8	5	7	6	7	9	5	7	3	4	7	7	3	5	6	2	5	2	6	5	6
	sum 0	27	6	7	7	13	9	15	14	11	10	14	16	16	5	7	20	8	7	15	7	14	6	7	7
	Total	0	3	6	4	4	4	0	-1	-2	7	-1	5	3	8	6	1	9	8	8	10	9	9	10	8

Kesselring matrix of system-concepts from morphological matrix

		Weight	System-concept 3		System-concept 10		System-concept 12		System-concept 14		System-concept 15		System-concept 17		System-concept 18		System-concept 19		System-concept 20		System-concept 21		System-concept 22		System-concept 1421		Final concept	
The SRS signal to airbag must be resistant to distrubances	Few connectors	8	3	24	3	24	3	24	3	24	3	24	3	24	3	24	5	40	3	24	5	40	3	24	3	24	3	24
	Low risk of connector gnuggning	8	3	24	4	32	5	40	4	32	3	24	5	40	5	40	4	32	5	40	4	32	5	40	5	40	5	40
Fastening and securing the steering wheel is crucial to driver safety	Able to verify mounting steering wheel	10	4	40	3	30	4	40	4	40	4	40	4	40	4	40	5	50	4	40	5	50	5	50	5	50	5	50
	Low risk of play in z-direction	9	3	27	3	27	3	27	5	45	5	45	3	27	5	45	5	45	5	45	5	45	5	45	5	45	5	45
	Able to verify mounting Airbag	6	2	12	2	12	5	30	4	24	2	12	2	12	2	12	5	30	2	12	5	30	2	12	2	12	2	12
Feedback to ensure build quality	Resistance to human errors (not easy to forget)	5	4	20	5	25	2	10	5	25	4	20	5	25	5	25	3	15	5	25	3	15	5	25	5	25	5	25
	Good Feedback to assembly personnel (sound vision)	7	4	28	3	21	4	28	4	28	4	28	3	21	3	21	3	21	3	21	3	21	3	21	3	21	3	21
New design reduces assembly time	Short Assembly time	7	4	28	5	35	2	14	5	35	4	28	5	35	5	35	3	21	5	35	3	21	5	35	5	35	5	35
	No additional tools needed	5	5	25	4	20	4	20	5	25	5	25	4	20	5	25	4	20	5	25	4	20	5	25	5	25	5	25
	Simplifies assembly operations	6	4	24	5	30	2	12	5	30	4	24	5	30	5	30	3	18	5	30	3	18	5	30	5	30	5	30
The locking function of the clockspring	Easy to unlock	8	5	40	5	40	5	40	4	32	5	40	4	32	5	40	5	40	4	32	4	32	4	32	4	32	5	40
	Easy to relock	6	5	30	5	30	5	30	4	24	5	30	5	30	5	30	5	30	5	30	5	30	5	30	5	30	5	30
	Cannot be accidently unlocked	5	2	10	5	25	2	10	4	20	5	25	5	25	2	10	2	10	5	25	5	25	5	25	2	10	2	10
	Able to lock in multiple positions	3	4	12	5	15	4	12	4	12	5	15	4	12	4	12	4	12	4	12	4	12	4	12	4	12	4	12
Moving parts must not interfere with any functions	Good guidance for loose parts (cables)	9	3	27	5	45	5	45	5	45	3	27	5	45	5	45	5	45	5	45	5	45	5	45	5	45	5	45
New design reduces overall cost	Low Number of parts	4	4	16	2	8	3	12	2	8	3	12	2	8	2	8	1	4	2	8	1	4	3	12	1	4	1	4
	Manufacturable	5	4	20	3	15	4	20	3	15	3	15	4	20	3	15	2	10	3	15	2	10	4	20	2	10	2	10
	Lower Cost	3	3	9	2	6	3	9	2	6	3	9	3	9	3	9	3	9	3	9	3	9	4	12	3	9	3	9
Guiding features for fast, easy and correct assembly	Low risk of vibration damping interferance	9	3	27	4	36	5	45	5	45	3	27	5	45	5	45	5	45	5	45	5	45	5	45	5	45	5	45
	Good visibility of assembly	6	2	12	2	12	4	24	2	12	2	12	2	12	2	12	4	24	2	12	4	24	3	18	2	12	2	12
	Provides possibility for more ergonomic assembly	4	4	16	4	16	4	16	3	12	4	16	4	16	4	16	4	16	4	16	4	16	3	12	4	16	4	16
	Many guiding features	6	4	24	4	24	4	24	5	30	4	24	4	24	5	30	5	30	5	30	5	30	5	30	5	30	5	30
The design needs to be compatible with future additions to the SW	Provides support for different sequences of assembly	4	5	20	5	20	3	12	2	8	5	20	5	20	5	20	3	12	5	20	3	12	2	8	5	20	5	20
One person alone should be able to assemble to complete SW	Criteria: Weight, reach, visibility, complexity of assembly	2	4	8	5	10	3	6	3	6	4	8	5	10	5	10	3	6	5	10	3	6	4	8	5	10	5	10
Theft protection	Easier to assemable than disassemble	7	3	21	3	21	1	7	3	21	3	21	3	21	3	21	1	7	3	21	1	7	4	28	3	21	3	21
	Total Score			544		579		557		604		571		603		620		592		627		599		644		613		621
	Procent of max			72%		76%		73%		79%		75%		79%		82%		78%		83%		79%		85%		81%		82%
	Rank			**11**		**8**		**10**		**6**		**10**		**7**		**4**		**9**		**2**		**8**		**1**		**5**		**3**

APPENDIX I. DFA ANALYSIS RESULT - FINAL CONCEPT

DFX report

	Preassembly of steering wheel - Final Concept	Issue:	
		Issued by:	
Product/part:	Steering Wheel without deco, switchpack and airbag		

	Need to assemble part	Gripping by hand	Reachability	Insertion	Tolerances	Holding assembled parts	Fastening method	Separate operations	Agg Score	Agg Score (%)	Time	Agg Time	Agg Time (%)
Steering Wheel without deco, switchpack and airbag									324	75%		45,3	252%
Steering wheel	9	9	9	9	9	9	9	9			3		
Cabels for switchpack and horn	9	9	9	3	3	3	3	9			6,4		
Switchpack left	9	9	3	9	1	3	3	9			10,9		
Switchpack right	9	9	3	9	1	3	3	9			10,9		
Deco	9	9	9	9	1	3	3	9			6,4		
Airbag module	9	9	3	3	9	9	9	9			7,7		

DFX report

	Assembly of Complete Steering Wheel inside the car - Final Concept	Issue:	
		Issued by:	
Product/part:	Steering wheel complete assembled		

	Need to assemble part	Gripping by hand	Reachability	Insertion	Tolerances	Holding assembled parts	Fastening method	Separate operations	Agg Score	Agg Score (%)	Time	Agg Time	Agg Time (%)
Steering wheel complete assembled									132	92%		9	150%
Steering Column	9	9	9	9	9	9	9	9			3		
Steering wheel	9	3	9	9	9	9	3	9			6		