CHALMERS
UNIVERSITY OF TECHNOLOGY

Designing the Cab Interior of the Future

Master's thesis in Product Development

CAIO FERNANDO SCHWALZ DO NASCIMENTO
ROHITH KALYANARAMAN

Design the Cab interior of the Future

Conceptual design proposal for a Cab living area in trucks that can be deployed in Volvo's future trucks

CAIO FERNANDO SCHWALZ DO NASCIMENTO

ROHITH KALYANARAMAN

Department of Product and Production Development
Division of Product Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Göteborg, Sweden 2016

Design the Cab Interior of the future
Conceptual design proposal for a Cab living area in trucks that can be deployed in Volvo's future trucks

CAIO FERNANDO SCHWALZ DO NASCIMENTO
ROHITH KALYANARAMAN

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

Cover:
[Final product – double bunk concept (p.56)]

Göteborg, Sweden 2016

ABSTRACT

This master thesis project was performed at Volvo Group Trucks Technology – Advanced Technology and Research at Driver Environment & Human Factors division. It was conducted at the Department of Product and Production Development at Chalmers University of Technology.

The aim of this master thesis was to generate a new concept for the living area of a future Volvo FH-series truck. From the customer point of view, the product developed must fulfill the needs presented by the new generation of drivers considering about ergonomic and design criteria's.

As deliveries, this project presents a conceptual layout and features that will make the FH-series most appealing and attractive for European drivers within the long-haulage industry. This project also presents a benchmarking of the Heavy-duty trucks market, profiles of possible future drivers and their needs.

The final product is a double bunk concept which enables drivers to travel for many days away from home and usually accompanied by co-drivers. These customers commonly want to have huge spaces for storage and would like to have a social area inside the cab.

Keywords: Volvo Trucks, Volvo FH, Living area, Concept.

ACKNOWLEDGMENTS

We would first like to thank our thesis advisor Mr. Andreas Dagman of the Product and Production Department at Chalmers University of Technology. He consistently allowed this paper to be our own work, but steered us in the right direction whenever he thought we needed it.

We would also like to thank our supervisors Ms. Ellen Hultman and Lina Andersson at Volvo Group Truck Technology for the collaboration and interesting discussions that have led to worthwhile insights and inspiration in our thesis work. We would like to thank everyone in the Department of Driver Environment and Human factors and Driver productivity for friendly and welcoming environment.

Moreover we would like to thank Mr. Karlsson Mats from product planning department in Volvo for enlighten us with knowledge about Volvo customers. We would like to thank Mr. Tomas Sandblom for extending us with the required help during surveying. We would like to thank Mr. Szalo Gabor, Michael Dahl and everyone at the Ergonomics department for extending us the appropriate support at right time and providing with guidance in all situations. We would like to thank Mr. Martin Agaeus for providing the after-market knowledge about the trucking industry. We would like to thank Mr. Peter Jaldelid for providing us with necessary tools needed to work on the Mock ups. We also like to thank few friends from Volvo Brazil who have also supported us during the course of our thesis work.

Finally, we are grateful to everyone in Chalmers and Volvo for supporting us and providing guidance at all situations.

1. INTRODUCTION

This chapter describes the background needed for a good understanding of the project, providing the problem statement and purpose/aim for the research. It includes the research questions covered through the work and the project delimitation by a specific scope.

1.1 Background

The Thesis Work was conducted at the department of Advanced Technology and Research (AT&R) at Driver Environment & Human Factors, a division of the Volvo Group – Trucks Technology.

Volvo Group is one of the world's leading manufacturers of solutions in many segments, like trucks, buses, industrial engines, construction equipment and marine engines. They are noted to be the pioneers in usage of new technologies in the market.

Volvo was an AB SKF subsidiary, the Swedish bearing manufacturer, in 1915. Gustaf Larson and Assar Gabrielsson, the two Volvo founders, decided to start a construction of a car to test bearings. Volvo was born officially on April 14 from 1927 (Volvogroup.com, 2016).

The brand Volvo Trucks history started in January 1928 with the first truck released, called the Series 1 that was quickly sold. The 1930's was a decade of expanded market, improving the quality of their products. Thereby Volvo had become the dominant truck manufacturer in the Nordic region (Volvotrucks.com, 2016).

Nowadays, Volvo Trucks is the second-largest heavy-duty truck manufacturer, delivering more than transport solutions (trucks) by creating the most safer, robust and luxury trucks in the market by eliciting the customer's needs. The brands of the Volvo Trucks are Volvo, Mack, Renault, Eicher and UD Trucks. They are strategically positioned based upon the regional requirements of the markets and brand recognition with plants in five continents and sold in more than 140 countries (Volvotrucks.com, 2016).

The Volvo core product for trucks is the FH-series. Volvo FH was release in 90's and is a heavy-duty truck oriented for a long-haul application. From the beginning, FH model has been awarded many times as "Truck of the year" in 1994, 2000 and 2014. The FH truck has highlighted its importance in Volvo's portfolio by selling more than 400,000 since 1993 (Volvotrucks.com, 2016). The Figure 1 presents the exterior of the FH truck.

Figure 1: Volvo FH-2016, cab exterior (Volvotrucks.com, 2016).

Volvo offers a wide range of FH variants, with different specifications and options available for drivers, to fulfill and deliver the best solution for oriented applications (Volvotrucks.com, 2016). The Figures 2, 3 and 4 present the Volvo current cab size for the FH series:

- Sleeper Cab (CAB-SLP): Interior height with 1710 mm, single bed:

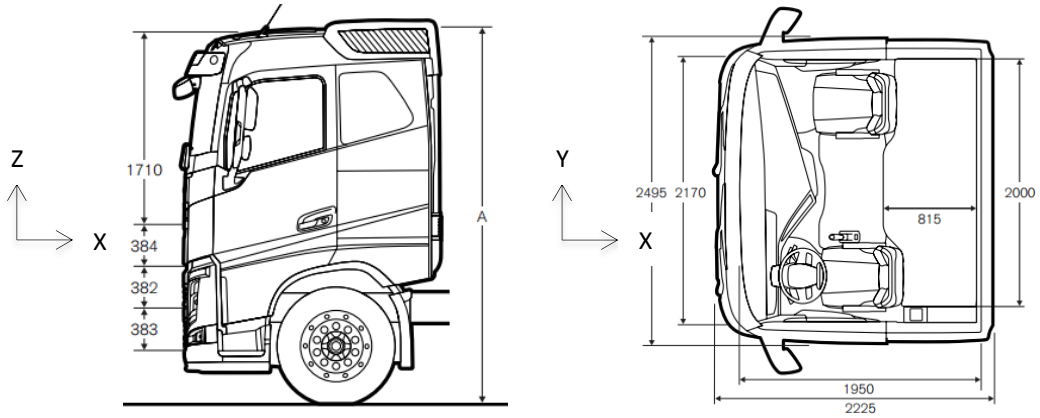


Figure 2: Volvo FH-2016, CAB-SLP dimensions (Volvo Group Trucks Technology, 2016)

- Globetrotter Cab (CAB-HSLP): Interior height 2030 mm, double bed:

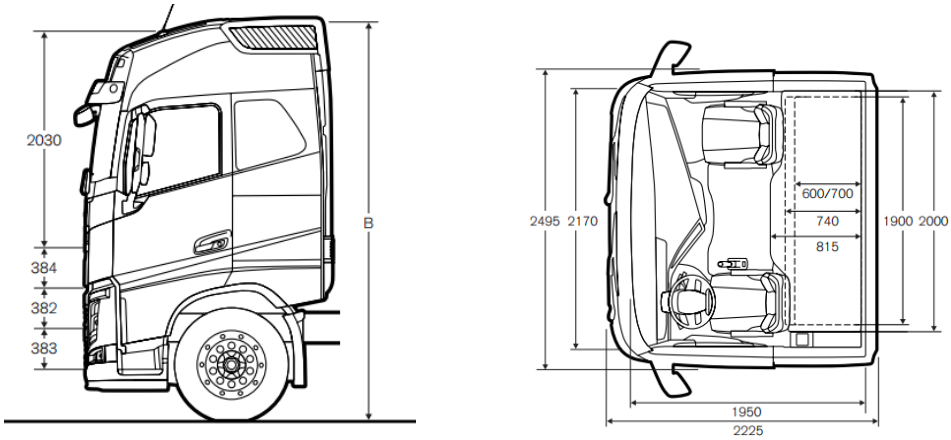


Figure 3 – Volvo FH-2016, CAB-HSLP dimensions (Volvo Group Trucks Technology, 2016)

- Globetrotter XL Cab (CAB-XHSL): Interior height 2220 mm, double bed:

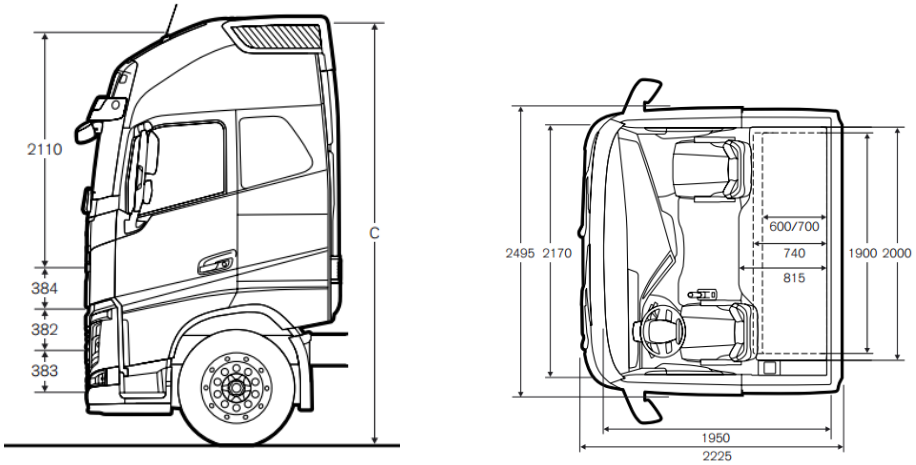


Figure 4: Volvo FH-2016, CAB-XHSL dimensions (Volvo Group Trucks Technology, 2016)

In terms of engine power, Volvo delivers seven options of engines that could be combined with all the cab sizes: 420, 460, 500, 540, 550, 650 or 750 horsepower, with manual or automatic gearbox (Volvotrucks.com, 2016).

The different cab size influences in the level of features offered inside the truck. A larger space implies in more availability for tools to be placed and more space created on the living area.

1.2 Purpose

The thesis proposal is a conceptual design for a truck cab living area. Based on the customer point of view, this thesis explores how a future truck cab interior can be designed to be the most appealing offer for haulage firms and drivers. Focusing on the given set of needs and cab dimensions, our work involves investigating and evolving the given material into a conceptual product. By new solutions or redesign, the truck living area must be optimized according to the customer needs.

1.3 Research questions

The project will be helpful in exploring how the current situation, changes in legislation, customers profile and future developments will influence the usability of the long-haul trucks.

Based on current product development process, customer needs and future, this project is focused on developing new set of solutions for the FH-series trucks.

Taking these aspects we formulate the following research questions that our thesis will answer:

Question 1: How can the living area for the future FH series be designed to be most appealing and attractive for future drivers?
The first question explains about how the company could create more value for the drivers through redesigning or by offering new products for the FH living area. The answer for this question is the concepts being developed by addressing the needs of the drivers, therefore presenting what is appeals and attractive.

Sub question 1: Who will be the future drivers and how the market for the long-haul application will be?
The answer is the characteristics of the drivers, their profiles and the environment that they will be working in the future. It is important to understand that for whom we are developing the products and how their needs are going to be addressed.

Sub question 2: Which customer needs should be contemplated in the living area to create an appeal and attractive FH truck?
The answer of this question explains the solutions in terms of functions and features inside the living are. This is achieved by prioritizing and solving the needs to be addressed.

1.4 Scope

The solutions will be implemented in cab interior from the future FH - Volvo Trucks model. The market selected is the European market for long-haul application. The concept developed must respect ergonomic requirements, user interfaces and predefined cab dimensions.

This project doesn't evaluate product design and provides recommendations for technical solution to the ideas generated.

The list of requirement and limitations provided by Volvo and defined by this project is available on the Section "3.1.1.4 Product constraints".

1.5 Time plan

In order to organize the work flow and deliveries, a Gantt-chart was created during the project planning phase. This chart provided a schedule which included 20 weeks of work plan. After revisions and development loops, the time plan was updated. In the beginning the knowledge about the product and market was collected for the project. Interviews with specialists, benchmarking and patent analysis helped the concept generation and evaluation. The final phase was dedicated for system level design of the concepts and for writing the report. Gantt-chart is available on Appendix A

2. LITERATURE REVIEW

This chapter presents the literature helpful to contextualize the project. The topics mentioned are the methods for develop products and the importance in have a step-by-step process, the developments in the cab interior that is going on in the market, the ergonomic aspects considered in a new cab interior and finally an explanation about the long-haul truck industry.

2.1 Product Development Methods

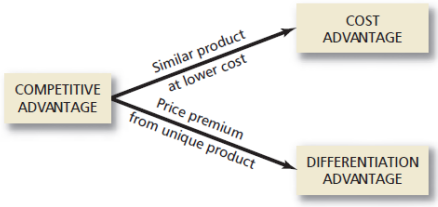
This review describe what is a product development method, which models are available and what the importance are in have a step-by-step procedure for develop a new product.

2.1.1 What is a product development method?

Product development is the set of activities where the result of the enterprise delivers something valuable to its customers. It begins with perceiving a market niche or opportunity going through the production and sale (Ulrich & Eppinger, 2012).

Product development processes are considered crucial to increase profit and reduce the time to develop new products by having competitive advantages (Stalk, 1988). Competitive advantage could be defined as ability to earn more market share than the competitors in the same market. This is achieved by appraising internal resources, identifying new opportunities in the market and fulfilling new customer needs. A strong product development process allows a firm to be ahead in product differentiation and deliver more technological and quality goods (Grant, 2010).

The Figure 5 explains the source of competitive advantages (Cost leadership and Differentiation) i.e. ways to achieve and company requirements. From the figure below is possible to see that product development is a key strategy element for advantage in product differentiation.



Generic strategy	Key strategy elements	Resource and organizational requirements
Cost leadership	Scale-efficient plants Design for manufacture Control of overheads and R&D Process innovation Outsourcing (especially overseas) Avoidance of marginal customer accounts	Access to capital Process engineering skills Frequent reports Tight cost control Specialization of jobs and functions Incentives linked to quantitative targets
Differentiation	Emphasis on branding advertising, design, service, quality, and new product development	Marketing abilities Product engineering skills Cross-functional coordination Creativity Research capability Incentives linked to qualitative performance targets

Figure 5: Sources of competitive advantage (Grant, 2010)

The need to have a systematic method is to create new products and defined design procedure that could end-up in a more valuable solution to the customer. The product development procedures must give a direction for how to solve the issue. It must be interchangeable between every type of design, facilitate the search for best solutions, provide guidance for decision takers (stakeholders) and finally must be ease to plan (Pahl & Beitz, 1996).

A systematic method must therefore foster product development abilities by increasing the creativity. However as described by Pahl and Beitz (1996): "Systematic procedures help in rendering design comprehensible and also enable the subject to be taught. However, what is learned and recognized about design methodology should not be taken as so many dogmas" (p.11). All these set of procedures described by the methods, make easier the structuration of the problem and translate him in tasks.

2.1.2 The different types of a product development methods

There are many methods in the product development field. Usually companies and designers use a mix of methods in order to fit one process for a specific development. They are dependent of several factors like: resources (tangible and intangible), user capabilities, industry orientation, etc.

Nigel Cross (2008) described two main approaches to draw up maps or models of a designing process:

- Descriptive models: commonly identify the significance to generate solutions in the first steps of the development process. This implies to a solution-focused nature of way to think the design. The primary solution is subjected to analysis, evaluations and loop developments. If the concept is not feasible it is eliminated and a new concept is developed, starting the cycle again. With heuristic characteristics, these models use

previous experiences, guidelines and rules to lead designers in right direction, without any guarantee for success (Nigel Cross, 2008). The Figure 6 is an example of descriptive designing method for product development described by French (1985).

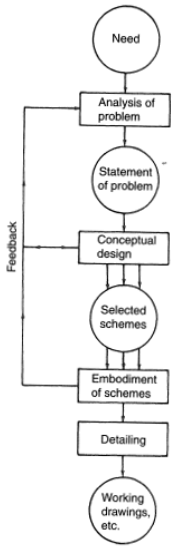


Figure 6: French's model – example of descriptive method (Nigel Cross, 2008)

French (1985) assumes that the evaluation stage doesn't provide necessarily a final solution or product. Sometimes a new and improved design has to be chosen, and iterative feedback loop is shown from the evaluation to generation stage (French & French, 1985).

- Prescriptive models: are latter models that are concerned with trying to persuade and encourage designers to use improved approaches when developing new products. Looking as algorithmic procedures, systematic steps are described to be followed. The idea is to ensure that the problem solving is fully understood, avoid neglecting important elements. These models are useful to transcript the whole process in inputs, outputs and tasks for each phase described (Nigel Cross, 2008).

  The Verein Deutscher Ingenieure (VDI) or Professional engineers' society, translating, provides a guideline in this area, suggesting a systematic approach. The design process, as part of product creation, is subdivided into general working stages, making the design approach transparent, rational and independent of the branch of industry, and could be used to illustrate this type of model (Pahl & Beitz, 1996).

  The VDI Guideline 2221 (1993) emphasized that, in each stage, the solutions should be analyzed and evaluated, showing clearly an orientation for tasks (Niger Cross, 2008). The Figure 7 presents an example of the VDI method, which is a prescriptive model.

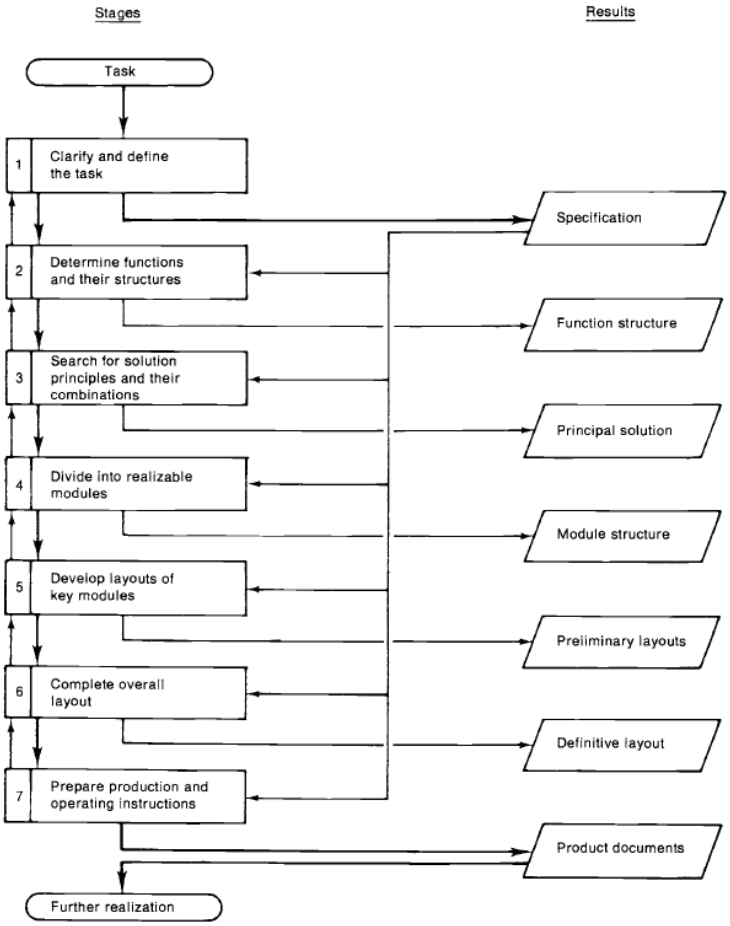


Figure 7: The VDI 2221 - Prescriptive model of the design process (Niger Cross, 2008).

These kind of procedure have been criticized, one time that the focus in on the problem, rather than on the solution.

Another well knows design methods are based in the prescriptive approach, highlighting the method described by Pahl and Beitz (1996), Stuart Pugh (1991) and Ulrich and Eppinger (2000).

Later on, in the chapter 3, the method used as base for this project is explained in detail.

2.2 Cab Interior Developments

Living area in a truck and what are the considerations that must be taken for an improved cab interior design are described in this topic.

2.2.1 Living area in a truck

With new technologies in the automobile industry, the life-time cycle of the products is becoming shorter (Referenceforbusiness.com, 2016). Adding a competitive flat-work to the truck industry, customer's requirements are becoming more important to fulfill. As a diary set of tools used by the drivers, the living area must be considerate as a key area for development.

Living area in a truck could be described as the area where driver can perform common activities like sleeping, eating, taking rest and every kind of actions in dynamic and static state of driving. It is an interface for the driver which provides bed, storages, fridge and even more facilities inside the vehicle.

In many instances drivers are out of their home for weeks and months. Consequently trucking becomes their lifestyle apart from their profession (Anon, 2016). In the Figure 8 is possible to identify the main areas on the living area of a truck.

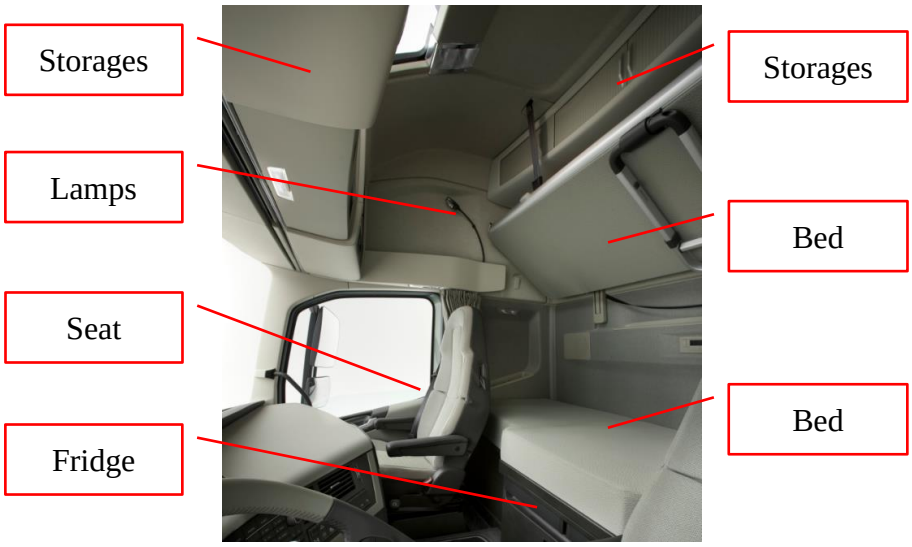


Figure 8: Volvo FH, cab interior and some features

All truck companies agree that the existing cab-layouts could be improved, in terms of ergonomics, to achieve a higher level of comfort for truckers (Rns.trb.org, 2016). Trying to decrease the efforts designers are looking for new solutions to access storages, enter inside the cab, more space to stand up straight, increase walkthrough area and other ergonomic requirements, one time that the most injuries reported resulting from fall or bad usage inside the cab (Archive.commercialmotor.com, 2016).

Moreover, truck manufactures are looking forward for new regulations that allows increase the cab size, adding an extra length and meaning more space available to dedicate new features or solutions, adding extra value for the cab (Kendall, 2016). These regulations are leading for an important point in the cab designs, flat floors (without the engine tunnel) inside the truck will be achieved, being a differential for the truck-makers (Kendall, 2016).

Another important point for cab designers is that the manufacturing technology will open possibilities to create more space inside the cab. By replacing regular buttons, clocks and controls with touchscreens, the dashboard size could be reduced, for instance. With traditional technologies for plastic injection, the investments costs in tooling are huge, so the current orientation is have fewer parts and less diversity between products. The industries in the past 20 years adopted common platforms to avoid this diversity, but the trend today is that successful companies have very flexible platforms that can be orientated for all the truck applications. ("Thinking inside the box", 2014)

2.2.2 Ergonomic aspects in new cab designs

Some of the things considered when designing a cab is, cab manufacturers have started the transition from using the traditional percentile approach to a multivariate accommodation model (MAM) (McGowan, 2012). The amenities and service points inside the cab have to comfortably accommodate body types (Dantas, 2015). The body types ranges from 5 foot, 2 inches, 110 pound female to a 6 foot, 5 inches, 300 pound male (Park, 2014). The ergonomically designed truck cabin is crucial in prevention of driver fatigue (Rns.trb.org, 2016). This would include safe access and entry into the truck cab. Figure 9 shows a relative size of different percentile humans.

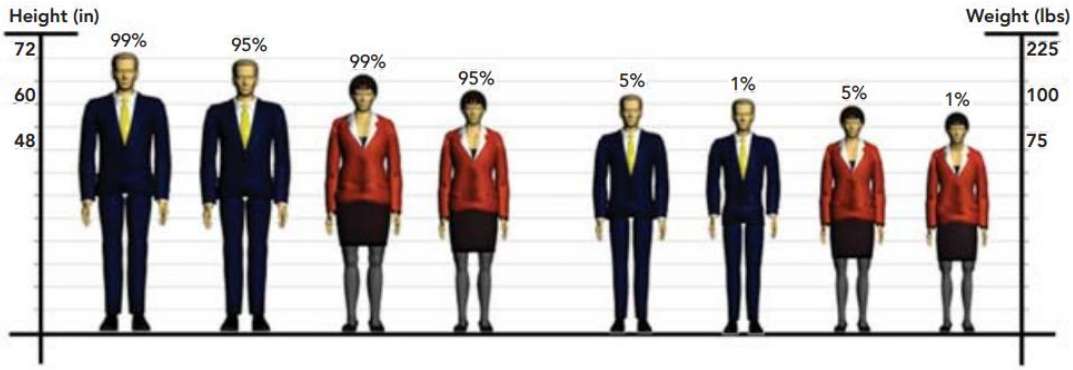


Figure 9: Relative size of different percentile humans (Allsteel & Allsteel, 2016)

The vehicle's interior must be adjustable to drivers of different shapes and heights. Some of the features include:

- The area of reach
- Sufficient head and leg room
- Height and seat position to improve the vision and eliminate blind spots.
- Reach the steering wheel without stretching the arms.

In many situations drivers perform their activities within a specified 3D space of fixed location which is referred to as work space envelope. It is described by the functional arm

reach of the driver and most of the things which they handle should be within this reach envelope.

The driver's eye vision is an important ergonomic criterion. According to SAE J985 human eyes (see Figure 10 and Figure 11) can generally turn 30 degrees before the head is turned.

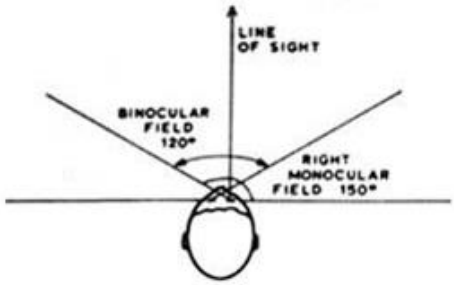


Figure 10: Binocular plane of eye (Sougata Karmarkar, 2016)

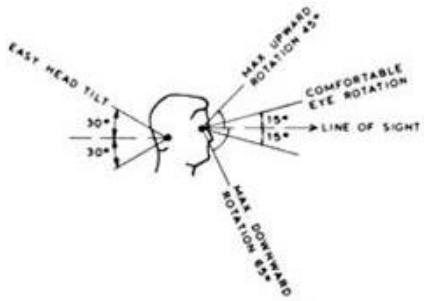


Figure 11: Horizontal plane of eye (Sougata Karmarkar, 2016)

The binocular vision of a driver could extend up to 120 degrees. In horizontal plane, the eye movement is comfortable within 15 degrees above or below the horizontal plane. It can see 45 degrees upwards and 65 degrees downwards if necessary. During the design care should be taken to provide maximum view all around either through direct vision or by means of rear mirrors and cameras (Sivaraman, 2016).

2.3 Long-Haul Truck Industry

The long-haul truck industry is described by deliveries that are farther than distance of a 160 km of radius from a home terminal (Anon, 2016). This industry is commonly operated by trucks that are under the category N in European regulation (Ec.europa.eu, 2016). The Table 1 presents the vehicles categories on Europe, describing the characteristic of each vehicle:

Table 1 – European Vehicles categories (Ec.europa.eu, 2016)

Category	Characteristic
M	Vehicles carrying passengers
N	Vehicles carrying goods

L	Vehicles with less than four wheels
T	Agricultural and forestry tractors and their trailers

The N category comprises motor vehicles designed primarily for carrier goods and is divided, as showed in the Table 2, into:

Table 2 – N category vehicles (Ec.europa.eu, 2016)

Category	Characteristic
N_1	Vehicles having a maximum mass < 3,5 tones
N_2	Vehicles having 3,5< mass < 12 tones
N_3	Vehicles having a maximum mass > 12 tones

Heavy-duty trucks (HD) are included in N_3category that constitute all types of heavy vehicles, being applied in vocations that require high Gross Vehicle Weight Rating (GVWR>16 tones), as long-haul demanding (Dieselnet.com, 2016).

The HD market sold around 1.65 million of trucks in 2015, with an increasing demand trend for 2016 in the Europe (Frost & Sullivan, 2016). Therefore, these most expensive products in companies' portfolios represent the core value and the first source of profits for truck-makers.

Internal sources from Volvo estimate that drivers working in this segment usually drive 600km per day. Thereby they spend more time away from home. Some drivers work throughout the week, going home for weekends. Others could stay away in a trip for months before getting back home. Long-haul drivers are usually under pressure for delivery on time and make a huge personal sacrifice since they are not with families, friends and special occasions (Schmidt, 2016). They spend a lot of time traveling on highways and commonly carry loads for more than two days before change (Dye, 2016).

All these aspects build specific and important products for the companies and for the market, highlighting the importance of the consumer and focus on their needs.

3. METHODOLOGY

In this chapter some procedures are deployed in this project. All the methods used in the product development steps are explained with the reasons and assumptions. The sequence in this chapter is in the same order as the project progressed.

3.1 Product development – Ulrich & Eppinger method

The methodology selected for this project was described by Karl T. Ulrich (University of Pennsylvania) and Steven D. Eppinger (Massachusetts Institute of Technology).

This methodology treats product development as an interdisciplinary activity that requires interrelation between these main areas of a firm (Ulrich & Eppinger, 2012):

- Marketing: section of a company that makes the interface between firm and customer. They also set market price and promote the product.
- Design: plays the lead role in defining the product that meets the customer need.
- Manufacturing: primarily responsible for designing, operating and coordinating the manufacture system to produce the product.

To develop a great product, a set of challenges is faced. According Ulrich and Eppinger, (2012) the challenges are:

- Trade-offs: Recognize understand and manage trade-offs to enhance the product success.
- Dynamics: In an inconsistent environment, with new products and technologies being applied every day, decision making is a challenging task.
- Details: Developing a product with low level of complexity requires a lot of important decisions.
- Time pressure: less time available to take decisions.
- Economics: Create a product appeal to customer and relatively inexpensive to produce

The Ulrich and Eppinger (2012) method, as a descriptive approach, is valuable in make decisions explicit and allows the whole team understands the decision rationale. It provides a step-by-step process and act as “checklist”, to include important issues. It is valuable as well creating records and documents.

In the Figure 12 is presented the six phases that must be adopted on this methodology.

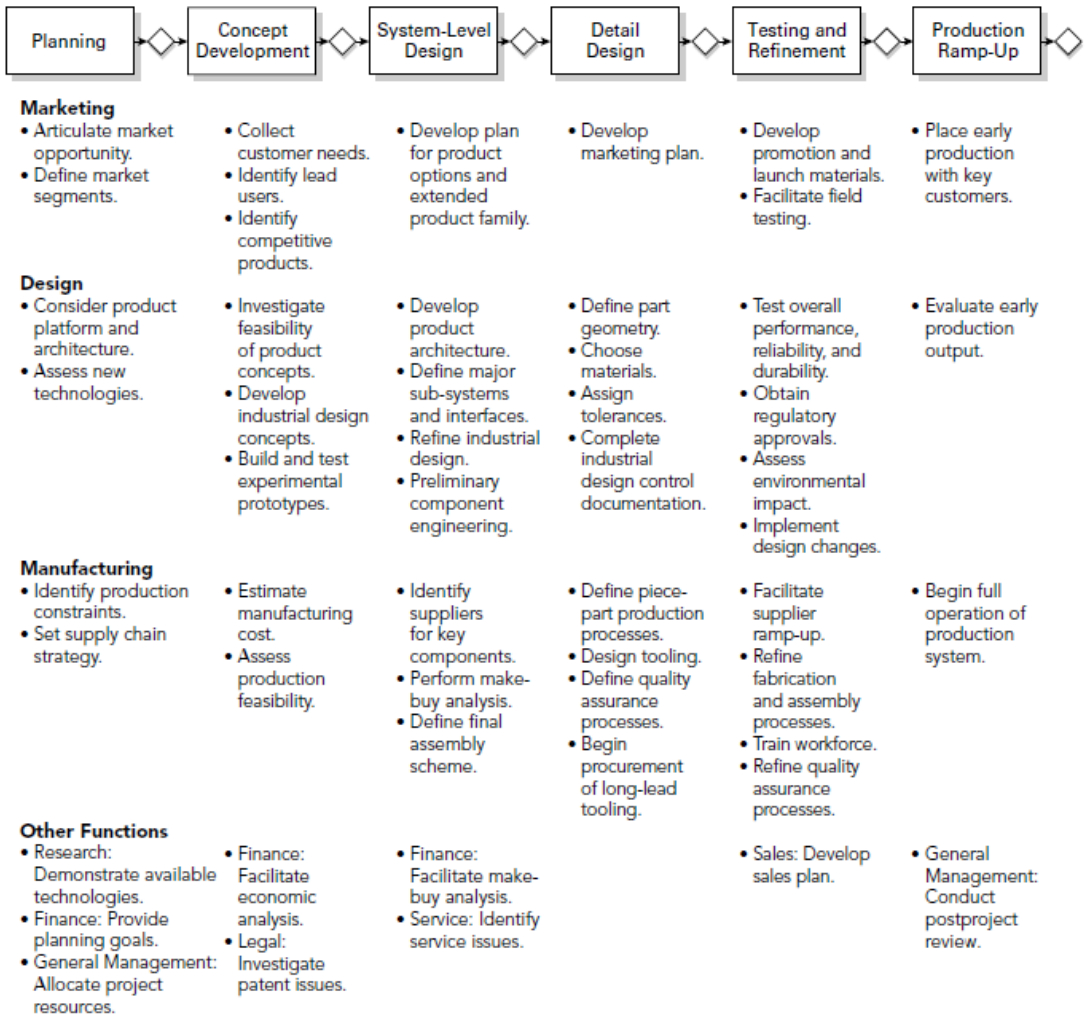


Figure 12: Generic product development process (Ulrich & Eppinger, 2012)

A generic method described by the authors, address six phases (Ulrich & Eppinger, 2012):

- **Planning:** begins with identifying the opportunities guided by a corporate strategy. It includes assessment of new technologies, market trends and objectives. The output is the mission statement which specifies the market constraints and key assumptions
- **Concept development:** the needs of consumer and the target markets are identified. Alternative concepts are created and evaluated, the function is described, features and specifications of the product are defined.
- **System-level design:** includes decision on the product architecture and how to splits the product into subsystems. As an output of this phase, the geometrical layout of the product, functional specification and a manufacturing process are delivered.
- **Detail design:** gives the complete specification of the product and identifies all the parts that must be bought from the suppliers. Tools for production are designed. The output for this phase is the control documentation (drawings or computer files describing the exactly geometry of the components).

- **Testing and refinement:** Involves construction and evaluation of the preproduction versions. With prototypes the questions regarding performance and assembly are answered.
- **Production ramp-up:** The product is made by the intended production system. The purpose is to train the work force and evaluate the assemble line by considering logistical issues.

In the concept development phase, more coordination among the functions is needed. Therefore Ulrich & Eppinger expanded this phase which is called as *front- end process.* This expanded phase includes the following activities presented on the Figure 13 (Ulrich & Eppinger, 2012):

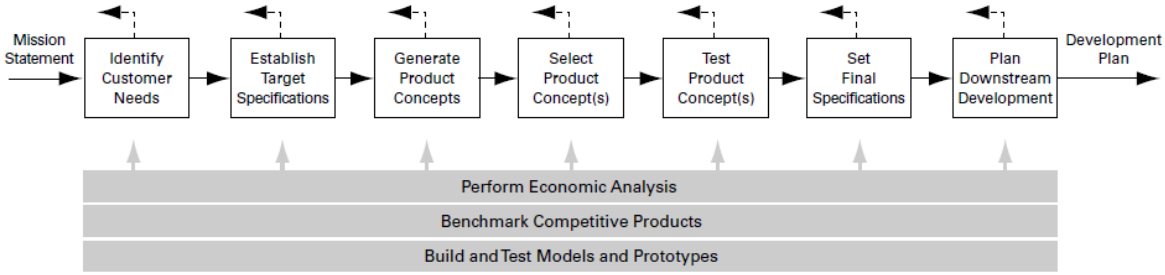


Figure 13: Front end activities (Ulrich & Eppinger, 2012)

Table 3 explains the activities in each stage of the concept development:

Table 3 – Concept development phases

Activity	Goal
Identify customer needs	Understand the customer needs
Establishing target specifications	Description of what the product has to deliver
Generate concepts	Explore the space of product concepts that address customer needs, including external searches.
Concept selection	Concepts are analyzed in order to identify the most promising concept
Concept testing	Concepts are tested to verify if the customers' needs have been met
Setting final specifications	Specify values of the metrics that reflects the constraints
Project planning	Detailed project schedule to complete the project

The process of development described in the Figure 13 is generic, however Ulrich and Eppinger (2012) cited that the processes used: "(…) will differ in accordance with the unique context of the firm and the challenges of any specific project." (p.18).

We decided to use Ulrich & Eppinger generic method with few modifications, since we have only twenty work weeks and the some phases of the method are out of the project scope. The first three steps (Figure 14) describe the methodology that we chose to fit our schedule with the level of maturity and scope of the project.

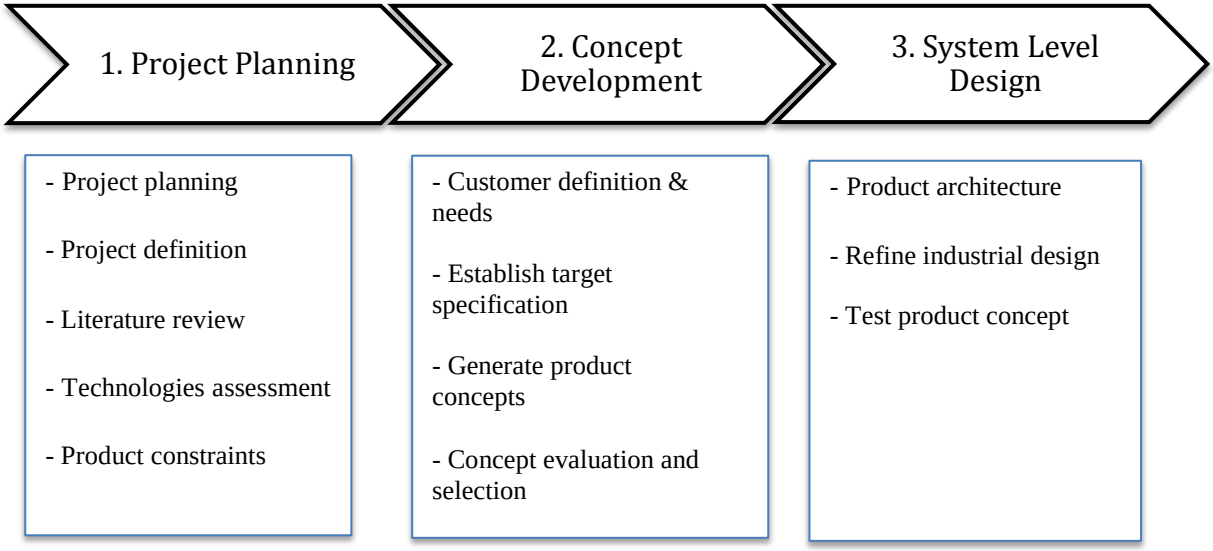


Figure 14 – Ulrich & Eppinger method edited

These phases use some frame work to achieve good results based on methodology described in the book which are explained bellow:

3.1.1 Project Planning

The project planning phase address the activities related with project definition, the literature review, technologies assessment and product constraints.

3.1.1.1 Project planning & Definition

In order to organize the work flow and define activities, this first action in the project planning phase was dedicated to create a time plan for the activities (Gantt-chart available in the Appendix A). As a part of project definition, meetings with Volvo and Chalmers supervisor's was held to present the opportunity, define the market segment, product model, scope of project, deliveries and to define the problem.

3.1.1.2 Literature review

To have more knowledge about the field a literature review was done. It addressed the importance of having a good product development process, the current developments in truck

and considerations in the living area. It also enlightened us with the market segment and customer segments included in the market scenario (section 2. LITERATURE REVIEW).

3.1.1.3 Technologies assessment

Industries related were analyzed. For example, customer who demands small living space or support for many days away from home was chosen. Therefore technologies involved in nautical industry, aerospace, motorhomes and small apartments were analyzed in order to identify ideas and solutions that would be useful for the project.

3.1.1.4 Product constraints

Finally, Volvo provided constraints and requirements that must be addressed, including target value when required. These constraints were described in order to achieve an ergonomic environment and define the project scope and were divided in different topics. Ergonomic and design criteria, that are requirements and desires from the company, were divided into requirements for sleeping space, characteristics of storages, walkthrough area inside the cab, usage & visibility and general (parts that must be kept the same, dimensions and functionalities).

3.1.2 Concept Development

The method and sequence of work for the concept development phase are based on steps of the front-end process. This phase started with customer identification and needs, then goes to establishing targets, generating concepts, evaluating, selecting concepts and finally testing them.

3.1.2.1 Customer identification & Needs

The first phase started with identification of the customers and their needs. Volvo provided a basic set of customer needs for the current FH-series. As the project address future drivers, it proved necessary the need to forecast the future drivers, influence of trend and new needs in the living area of the truck. Therefore, to identify the future profile and future needs of drivers, a generic method to create future scenarios. The Figure 15 highlights the phases that must be followed for a trend analysis.

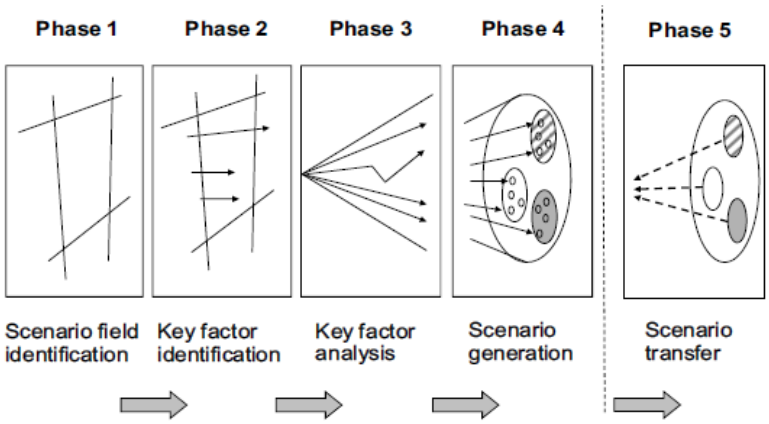


Figure 15: General scenario process in five phases (Kosow and Gaßner, 2016)

A scenario is defined by describing a possible future and their characteristics. This helps to assess the future with set of strategies and take right decisions to draw possible paths for future developments (Kosow and Gaßner, 2016).

On project this method was used as a base to create the customer needs. We analyzed the technologies, regulations and demographic aspects of long haul segment which has effects on driver lifestyle, their needs and usage in the living area of truck. It helped us to build the profile of future customers.

Face- to- face and partial structured interviews with experts were conducted inside company to gather the characteristics for the product usage and customer. Volvo employees from Product Planning, Feature Verification & Validation and from Advanced Technology & Research were selected. It was helpful for us to track the future product portfolio (Product Planning), performance of the current FH-series (Feature Verification & Validation) and technologies in the market (Advanced Technology & Research).

Despite that, customer data from Product Planning department regarding surveys and clinics that Volvo has performed was collected in order to have a deep knowledge from the customer. Therefore, the future profile of customer was created and the first set of needs (provided by Volvo) was reviewed in order to create the future driver needs.

3.1.2.2 Establish target specifications

With a new set of customer needs it was possible to establish targets specifications. The Volvo constraint list was reviewed in order to refine and select the requirements that were addressed on the project. A complete list of requirements was created with product specifications. An example of requirement list is presented in the Figure 16 (Ulrich & Eppinger, 2012):

No.	Metric	Unit	Value
1	Attenuation from dropout to handlebar at 10 Hz	dB>	12
2	Spring preload	N	600–650
3	Maximum value from the Monster	g	<3.4
4	Minimum descent time on test track	s	<11.5
5	Damping coefficient adjustment range	N-s/m	>100
6	Maximum travel (26-in. wheel)	mm	43
7	Rake offset	mm	38
8	Lateral stiffness at the tip	kN/m	>75
9	Total mass	kg	<1.4
10	Lateral stiffness at brake pivots	kN/m	>425
11	Headset sizes	in.	1.000 1.125
12	Steertube length	mm	150 170 190 210 230
13	Wheel sizes	List	26 in.
14	Maximum tire width	in.	>1.75
15	Time to assemble to frame	s	<45
16	Fender compatibility	List	Zefal
17	Instills pride	Subj.	>4
18	Unit manufacturing cost	US$	<80
19	Time in spray chamber without water entry	s	>3600
20	Cycles in mud chamber without contamination	k-cycles	>25
21	Time to disassemble/assemble for maintenance	s	<200
22	Special tools required for maintenance	List	Hex
23	UV test duration to degrade rubber parts	hr	>450
24	Monster cycles to failure	Cycles	>500k
25	Japan Industrial Standards test	Binary	Pass
26	Bending strength (frontal loading)	kN	>10.0

Figure 16: Example of final list of requirement (Ulrich & Eppinger, 2012)

A final list of requirement describes the requirements in metrics, the ways to validate the requirements and a value to be used as a target. In our project a reasoning to deploy each requirement was presented.

3.1.2.3 Generate product concepts

As methodology to guide the concept generation, a 5-steps approach was selected as described by Ulrich and Eppinger (2012). Due to the scope of the project, the first three steps were selected, as presented below on the Figure 17.

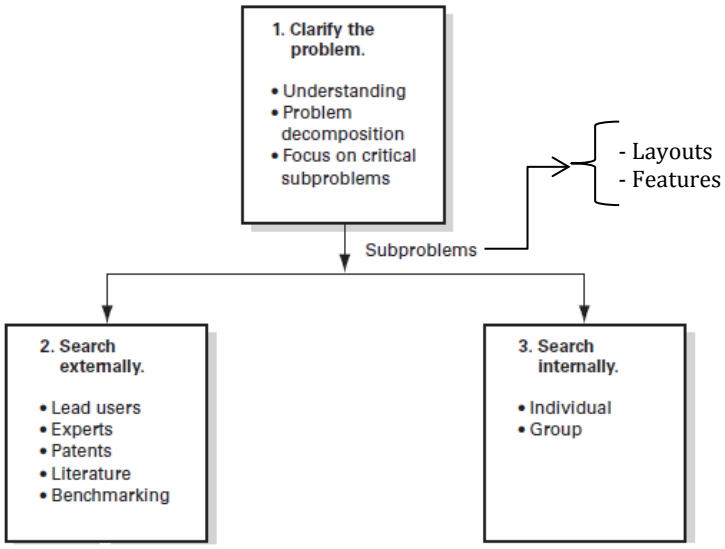


Figure 17: Tree first steps of concept generation – adapted (Ulrich & Eppinger, 2012)

The 3-steps approach breaks complex problems into sub problems. Then conceptual solutions are identified for the sub problems by internal and external sources (Ulrich & Eppinger, 2012).

For understanding the functionality of the living area and identify the functions inside the cab, a function means tree was done. This method allows designers to break down or decomposes the problem. The function means tree is the first step in concept generation phase to highlight the primary function of the product. This method (as showed on the Figure 18) graphically represents the entire solutions (Summers, 2016). There are two kinds of nodes used: functions (what need to be done) and means (how to achieve the needs).

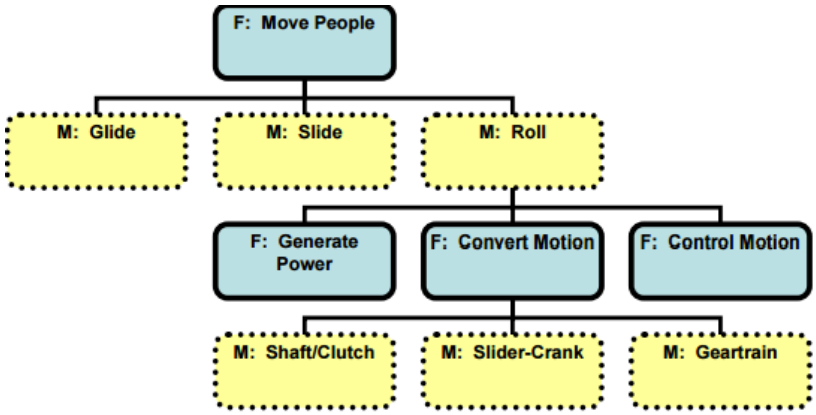


Figure 18: Function means tree example for a People mover (Summers, 2016)

After analyzing the function means tree, two different types of demands emerged. One regarding the ergonomic environment inside the cab (layout) and other is the tools needed to support activities inside the cab (features). Therefore, it was decided split the concepts generation into two loops of development: *layout generation* and *features generation.* This was done to decompose the problem, as presented in the step 1 (see Figure 15). The problem clarification, as described in the Ulrich and Eppinger (2012) model, helped us to exclude

concepts and ideas that neglect important aspects like safety, ergonomic, product feasibility and customer preferences.

Another frame work that encourages to divides the concept generation into layouts and features, in our case is the V-model (Figure 19). During the integration of system in their respective levels, this model allows that tests could be held, confronting the constraints and requirements with the product/interface being tested (Fogaça Truyts, Alves Simão de Lima, Motta, Tomassoni Coelho, & Franco, 2013).

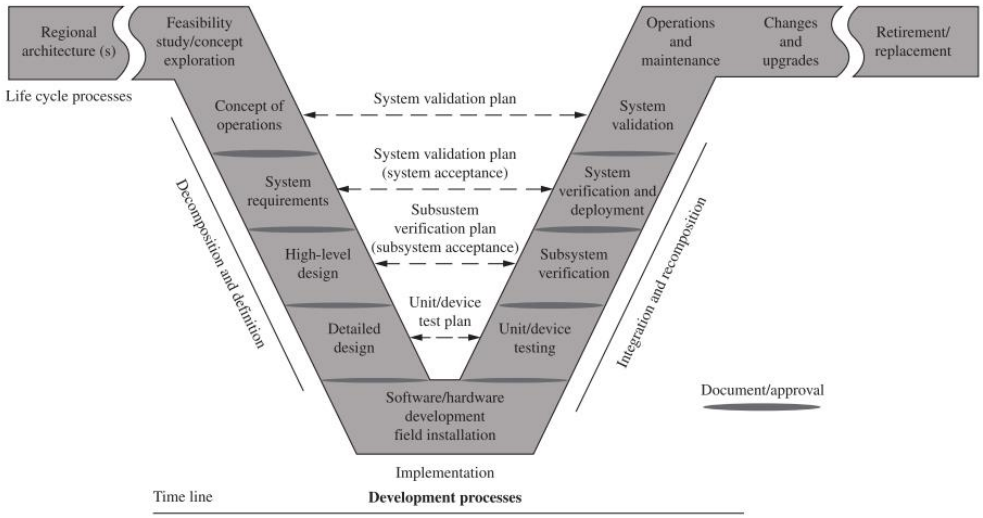


Figure 19: Model V diagram (Fogaça et al. 2013)

Taking the reasoning's into account, we can explain about the levels adopted:

- **Layout generation:** In this phase the possibilities to create a new environment inside the cab was evaluated, respecting the ergonomic requirements from Volvo. It concerns at the ergonomic aspects of the cab like clearances, walkthrough area, access, i.e., requirements used by the drivers but not directly perceived by them. As delivery, this phase presented concepts for some main areas defined:
    - Space for storages or features: spaces in the living area that were dedicated for storages or features.
    - Space to sleep: space in the living area where drivers and co-drivers could sleep.
    - Seats: how they could interact with the layout

  The important aspects adopted to guide the ideation were feasible ideas, complexity and customer preferences regarding an ergonomic environment.

  To generate ideas and concepts for interior solution, Volvo provided a wooden mock-up (Figure 20) from the cab with the real product dimensions that was described in the requirement list. By using foam layers we replicated the exact dimensions of the storage boxes and the bed size present in the current FH series truck. The main

features inside the cab were retained which created new possibilities for positioning and redesigning.

Figure 20: Wooden mockup

After analyzing a list of ergonomic requirements, dimensional and design criteria's stated by the company, a drawing for the living area was done and is presented in the Figure 21. It was helpful to identify the areas of opportunity by considering the constraints.

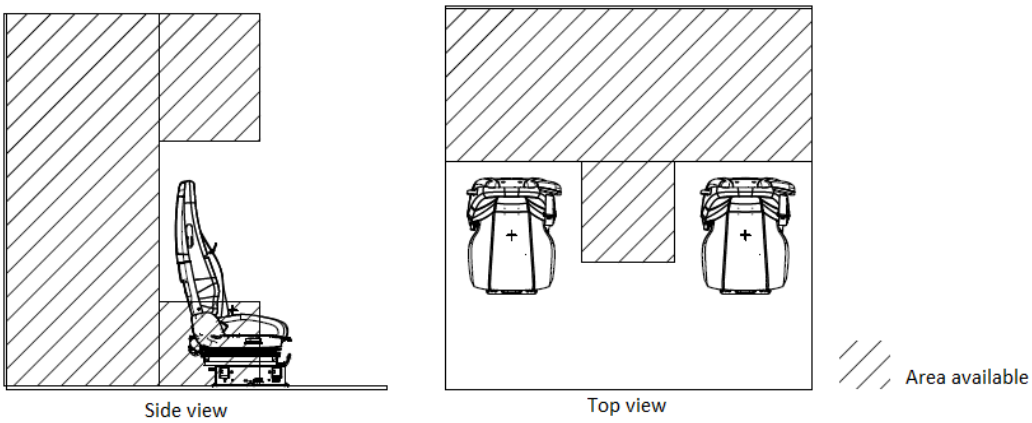


Figure 21: Area of opportunity identified

To generate layouts brainstorming session were held creating concepts for the layouts. The session was held inside the mock-up by making use of trucks seats, foams and the boxes. This was done to perceive the feeling of space and evaluate physically the postures and mobility inside the cab.

To document and present the concepts, pictures were taken and CAD models done using CATIA V5. Stakeholders from Volvo Ergonomic team, Cab Engineering, Product Planning and Advanced Technology and Research were invited to look the concepts mounted in the mock-up.

The next development loop is to select the solutions, features and shapes for the functions that are planned to be mounted on the dedicated spaces:

- Feature generation: After defining the layout, features and the main shapes of the solution were designated to specific space. The defined solutions are directly perceived by the drivers. To illustrate, let's use a fridge as example. The customer perceived the usage of the feature when he wants fresh water by evaluating the size and power of the fridge. Therefore, this loop defines the feature that will be fitted in the specific space defined during the layout generation.

  Based on the function means tree created for the usage of the living area, was created using morphological matrix in parallel with the layout generation. This was done in order to combine the features that are in the cab. The morphological matrix present solutions for the sub-functions identified in the function means tree. All the solutions available in the market were considered while solving the problem (Fargnoli, Rovida & Troisi, 2006).

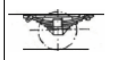
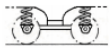
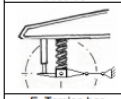
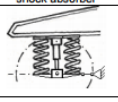
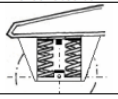
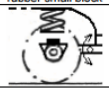
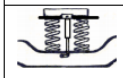
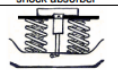
N°	FUNCTION	ACTUATORS			
1	To connect the wheel-set and the carriage	A Carriage spring	B Bogie	C Bogie with single-stage suspension	
					
2.1	To allow the primary suspensions simultaneously working)	A Coaxial helical springs + shock absorber	B Helical springs working in parallel + shock absorber	C Helica springs working in parallel + shock absorber	D Pressure spring + rubber small block
					
		E Torsion bar +helical spring + rubber small block	F Absent	G Absent	
			Single-stage suspension with bogie	Bogie is absent	
4.2	To reduce oscillations between the bogie and the carriage frame (secondary)	A Helical springs working in parallel + shock absorber	B Coaxial groups of helical springs working in parallel + shock absorber	C Coaxial helical springs + shock absorber	D Pressure springs (torpress)
					
		F Absent	G Absent		
		Single-stage suspension with bogie	Bogie is absent		

Figure 22 – Example of a morphological matrix (Fargnoli, Rovida & Troisi, 2006)

Some solutions proposed were excluded for the combinations due to a lack of safety, ergonomic, feasibility and comfort. The features selected were modeled and added in the selected layouts for evaluation.

To have more insights in generating concepts a benchmarking between the current long-haul trucks was made. To identify suitable layout conducted to identify strengths in competitors' products and to elicit similar types of solution. Since the project address the future, a benchmarking for conceptual future trucks presented officially by the truck-makers was done. The focus, were in the optional environment that the companies offer for customers in their activities and needs inside the cab by identifying common proposals. Visit in physical truck models from Volvo and from competitors was relevant to get to know the technical data from the trucks that compete in the same market.

The knowledge from the industries and a patent analysis was done. It was from different industries that have same similar customer's needs.

3.1.2.4 Concept evaluation and selection

Different concepts were evaluated using as a base customer needs. In this phase meetings was held with Volvo supervisors and stakeholders to evaluate each concept generated. As the scope is related with the purposing of new layouts for a future truck, the product design and shapes were not a focus on evaluations and selections. The concepts selected were chosen according to the customer's needs and some of these were combined in order to fulfill expectations and allow an improved interaction between driver and the living environment. Therefore, a Pugh matrix method (Figure 23), with some modifications, was selected as base for the selection.

The purpose of this method is to narrow the number of concepts quickly and to mature concepts. First step to prepare the matrix is necessary to input the criteria that must be used to compare the concepts, after that, one reference concept or product is used as base to compare the concepts generated regarding the selection criteria. Then, the concepts are rated using simple code, + for "better than", "0" for "same as" and – for "worse than") (Ulrich & Eppinger, 2012). However in this project, the criteria were not ranked and weighted since the scope is evaluate the ergonomics for a new cab interior, therefore the ergonomic aspects have the same level of importance to provide the best work-place in this aspect.

	Concepts						
Selection Criteria	**A Master Cylinder**	**B Rubber Brake**	**C Ratchet**	**D (Reference) Plunge Stop**	**E Swash Ring**	**F Lever Set**	**G Dial Screw**
Ease of handling	0	0	–	0	0	–	–
Ease of use	0	–	–	0	0	+	0
Readability of settings	0	0	+	0	+	0	+
Dose metering accuracy	0	0	0	0	–	0	0
Durability	0	0	0	0	0	+	0
Ease of manufacture	+	–	–	0	0	–	0
Portability	+	+	0	0	+	0	0
Sum +'s	2	1	1	0	2	2	1
Sum 0's	5	4	3	7	4	3	5
Sum –'s	0	2	3	0	1	2	1
Net Score	2	–1	–2	0	1	0	0
Rank	1	6	7	3	2	3	3
Continue?	Yes	No	No	Combine	Yes	Combine	Revise

Figure 23: Pugh matrix example for a syringe (Ulrich & Eppinger, 2012)

After rating the concepts with the purpose of select one or more to go ahead, the sum of + and – is done. In general concepts with more pluses and fewer minuses are ranked higher, however the team that is evaluating can identify criteria that really seem to differentiate the concepts.

The reasoning to use only the Pugh as method to evaluate and select concepts is due to the low number of concepts generated. With a broad scope, very constrained project and assumptions adopted it was unnecessary create unfeasible proposals.

During the selection, as a reference was used, i.e. the current Volvo FH-series to compare the concepts. Meetings were conducted with Volvo supervisors in order discuss about the ratings of the concepts.

3.1.3 System level design

This phase was dedicated to improve the maturity of the layouts evaluated and fit the features selected by the morphological matrix. Improvement on the CATIA V5 models was performed, as well as ergonomic considerations in terms of product platform and evaluations through DELMIA, a workbench of CATIA responsible for ergonomic analysis. For render pictures was used VRED, software for developed by Autodesk.

The results of this stage will be presented in terms of product review, showing the usage of the concept in one driver's day and the specifications considered about the product.

3.1.3.1 Product architecture

Considerations in the product modularity were taken in order to standardize parts and re-use solutions already provided by Volvo. The aim is use the same component or solution in many products. This allows the firm to manufacture or order higher volume, earning in terms of economy of scale. As procedure, some features and the access to them were selected a priority to build and disposal the other features.

3.1.3.2 Refine industrial design

Appearance (form, lines and proportion) and utility (human interfaces and usability) of the features and solutions considered were proposed. This phase, through software modeling, more realistic environment is provided.

To improve the final concept visualizing, the models were rendered, using VRED software, in order to give a realistic view of the cab interior and his usage.

3.1.3.3 Test Product concept

By DELMIA software evaluations regarding the driver positions and postures were done for a refinement of the concepts. Body profiles based in the customers were chose to evaluate how the concept selected performs in terms of ergonomics (accesses, postures, clearances, etc.). Images were taken in order to illustrate the spaces available for drivers.

4. RESULTS

In this chapter the results of each procedure described on the methodology are presented. The results will follow the methodology steps of the Ulrich & Eppinger adopted: project planning, concept development and system-level design.

4.1 Project planning

Apart from the Literature Review (section 2), the following results are part of the project planning phase.

4.1.1 Technology Assess

Industries that provide solutions for the same needs that drivers face while traveling in a truck were analyzed. This was done in order to identify what are the available solutions in the market for these customers who stay away from home for days. Some of the technologies selected for this analysis were

Motor-Homes: was noticed that, in general, motorhomes try to transmit the real feeling of a house, considering a smaller space. Using the same materials and shapes of home furniture, are focused in provide solutions for those who want to enjoy the trip without time compromise. The class C of motorhomes (Figure 24 and 25) is the smallest on the market and it was used to analyze (Kirkpatrick, 2012).

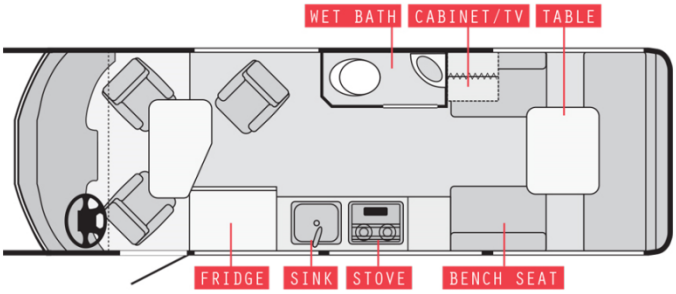


Figure 24: Mercedes Sprinter Roadtrek CS (Carlson, 2015)

Commonly as features for living, provides air conditioner, microwave, gas stove, kitchen and bath sink, fridge, toilet (dry or wet flush), bench, sofa-beds, television and storages quite similar of home solutions.

Figure 25: Mercedes Sprinter Roadtrek Adventurous CS (Carlson, 2015)

Small apartments: in restrict and high-value neighborhoods, small apartments are the trend for living or stay for few days (Porterfield, 2013). This reduced space need allow residences perform the same activities as they do in common houses. It was possible to check that the solutions are foldable or hided inside storages, as shown below:

Figure 26 – Foldable furniture "Kenchikukagu"– Atelier OPA (Designtaxi, 2016)

The space constrained implies directly in a higher effort for customer, one time that these kind of solutions need to be mounted every time to use.

Nautical industry: for travellers that use small sailboats, companies provide solutions quite similar of motorhomes (Wifi onboard, 2016). Using wood furniture, the focus is transmitting the feeling of a real house (Dufour-yachts.com, 2016). It is available for the customer solutions for toilet, sinks, stove, microwaves, beds, sofas, tables, fridges, etc. everything proof of water.

Figure 27: Interior of a sailboat (Wordpress, 2016)

All the industries in their respective area converge for the same type of solution, based in wood furniture, foldable or mountable features, without apply new technologies in manufacturing. They prefer simple technical solutions with technologies that have being used in the few years, as composite toilets, rigid sinks and gas stoves.

4.1.2 Product constraints

To provide first boundaries for the project, Volvo provided a list of requirements and design criteria to be contemplated and narrow down the scope.

Criteria related with the interaction between the driver body and the environment (ergonomics, usage & visibility, etc.), for achieve a physically safe living area were provided. These instructions follow the company desires and recent developments for the FH truck. The Table 4 presents the requirements from Volvo divided into related areas. It is important to state that "Generic" values are measurements without a target provided.

Table 4 – Volvo ergonomic requirements

Sleep area	**Value/Target**
Sleeping dimensions	2000 x 900 mm
No protruding object with radii smaller than	Min. radii 7 mm 0-230 mmm above bed. - can be changed
Sleeping height with adjustable top bunk in lowermost position	Min 550 mm
Mattress width at minimum dimension	Min 700mm
Fully foldable top bunk in applicable variants. It could be fully foldable against the wall and should have a reachable fixation in that position.	Generic
Storages	
Rear wall storage	Depth. Min. 190 mm Opening min 65.5 mm in x-axis. Top of storage shall be min 170 mm under top bunk.
Rear wall panel storage, weight of stored items	Density 0,3 (10 l storage= 3kg)

Rear wall panel storage, forces that can be applied by user in bunk	300 Newton
To have handle in under bunk storage with finger grips. It should be possible to slide out the refrigerator without any kind of hurdle.	Min 80 mm wide. Max 50 mm in from front edge of bunk. Generic
To have good storage capacity	>1000 liters
Walkthrough	
Walk through and moving around in the cab should be there.	Generic
Nothing should protrude above seat cushion level and hinder the movement.	Generic
Nothing should stick up above or forward of seat cushion level and hinder the movement.	Generic
Usage & Visibility	
The contrast between dark and light areas shall be soft (no sharp edges)	Generic
Visibility - target angles a-pillar	Angles must not be changed
Visibility - upward visibility	Angles must not be changed
CCP and climate control panel should be visible from bunk	Generic
The backrest of seats should be quickly foldable and should be moved away from the living area	Angle for adjustments
The control(s) shall be reachable and visible from the living area for all targeted users (F05 to M99) and should have enough clearance around them for easy operation.	Generic
The size and shape of the control(s) should allow for comfortable operation of the functions.	Generic
The force needed to operate the control(s) should be higher than the current vehicle	Generic
If the folding mechanism is electrical, the speed should be significantly improved as compared to the current vehicle. The electrical folding mechanism needs to work when truck is in off Mode (or Living Mode).	Generic

General requirements in terms of areas inside the truck or characteristics that must be kept without modification were proposed. Due design limitation or engineer request areas as the shape of the seats, dashboard, storage with exterior access must be kept or not take as a scope of the project. A different range of anthropometric data must be used for ergonomic evaluations. The Table 5 presents the design criteria that must be used regarding general aspects.

Table 5 – Volvo general requirements

General	**Value/target**
To keep the current dashboard design	Generic
Cab dimension	FH XHSL Cab + 300 mm in the length
To have features like radio, tachograph in the front shelf - above the drivers head	Generic
To have side storages with exterior access	Generic

If considered, microwave must be placed in the front shelf	Generic

These requirements presented were discussed and reviewed in order to fit with the project scope, showed-up helpful to identify and define the areas to assume as areas of opportunity, highlighting solutions in related industry, new technologies and the competitors that shall be looked to get ideas and improve the driver environment. It was also used to get more knowledge about the current FH-series.

Few customer needs were also proposed by Volvo to elucidate common activities that drivers perform, guiding the project research. The set of needs were divided into main topics that explain the usage of the living area:

- **Have comfort:** a truck interior cab should provide sit and relax comfortably, comfortable sleep/rest that allow driver to change postures and have privacy inside de cab.
- **Have space:** driver should be able to move (walk) easily in the cab, have space while work office, space to stand to straight, area to dress/undress and space to exercise.
- **Eat & drink:** Holders for plate and glass, tools to prepare food, storage for snacks, storage food and beverage cold.
- **Keep the hygiene:** keep daily hygiene (personal and cab), store garbage, water access and dry and warm up clothes or textiles.
- **Have fun and socialize:** interact with people, practice hobby activities and an interior cab that divide the work and leisure time.
- **Organize stuff:** something that holds and store office work stuff, store items by driver seat, store items by resting place, store valuable stuff.

As the requirements, the needs were discussed and will be reviewed, using as base information about customers and forecasting the future.

4.2 Concept development

The results about the concept development are explained, following the order of steps described in the methodology.

4.2.1 Customer definition & needs:

The results for this step are used to describe the future Volvo FH customers, through forecast the future and interviewing Volvo experts. The outputs are the customer profile and customer needs reviewed.

4.2.1.1 Future Forecasting and Scenario

The profile definition for the European driver is important to forecast the future that drivers will be embedded in. The profile and the driver needs will be influenced by the characteristics sought by transport firms, technologies available for companies in developments, healthy and demographic aspects of the population and the regulations imposed by the government. These areas might create new customer needs or perhaps change the current needs presented.

The group keeps the analysis based on the customer point of view, this means the customer expectations and requirements, understanding how these may create new demands for the developments in the FH living area.

Therefore, following the presented methodology, a forecast of the future was conducted in order to track trends and points that could build the use for drivers in the future cab. After identifying the scenario from the scope and constraint list, the key important factors (phase 1 – see Figure 15) are presented in the Figure 28.

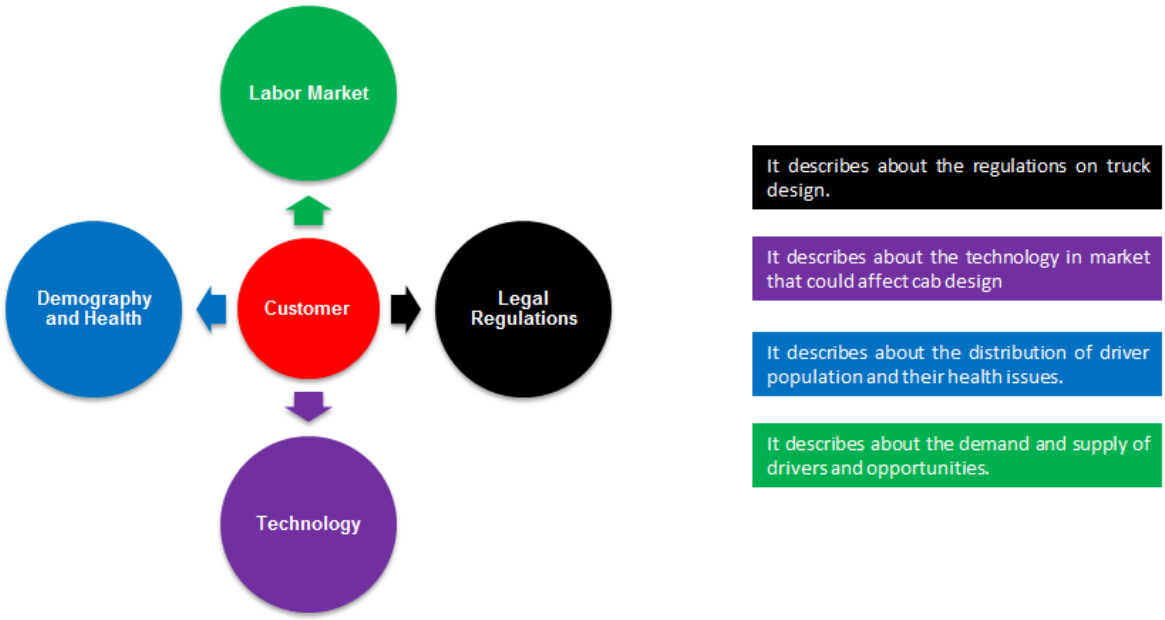


Figure 28 – Key factors identified – Phase 1 of the methodology applied.

The results of the key factors analysis are presented with the assumption of the most important points of each key factor. For a better understanding, this phase represents the phase 2 of the method used to forecast scenarios and make trend analysis (see Figure 15).

Legal regulations: Semi-trailers will have the cab length increased till 2022. The proposal of the European Union is set as mandatory new designs of the cab trucks, allowing companies achieve more comfort and aerodynamic shapes to reduce fuel consumption. According to information published by the EU the new design allows 12% of improving in the aerodynamic flow, which could create between 2-5% of fuel saving (Kendall, 2014).

The revision is addressing the design of one larger windscreen to reduce blind spots, also includes weight sensors, radars and cameras to improve cab safety (Kendall, 2014).

Labor market: Europe, in general, is facing a driver shortage. Some forecasts estimated that around 40% of professional drivers will be retiring in the next 10 years. This trend will lead for a shortage of qualified truck drivers in key markets. Some of these markets, like UK and Germany, already are facing problems with the lack of drivers (Boagey, 2014).

To attract skilled driver, some German companies are paying more to get skilled drivers, thereby the additional cost it's being passed to clients.

Some reasons for the shortage is the poor image of the truck driver career, some people don't see this kind of job as important, thereby companies are facing problems to recruit young drivers. Another problem is the low payments that drivers are receiving (Weiss, 2013).

Demography: The driver shortage will lead for the recruitment of younger drivers. This generations that have as characteristics the demand for a balanced work-life, big targets of what they want to achieve in their careers and a requirement in being always social connected, don't feel attract in be a truck driver, a time that some of those characteristics aren't found in the roads (Boagey, 2014).

Already 25% of drivers are older than 55 years and only 2% of the drivers are younger than 25 years, then the challenge is make this job interesting enough to bring more young drivers. One time that the young people become driver, the lack of experience will be a problem for the companies, thereby future truck should fulfill this lack and also address features that may make the truck driver career more attractive. For example, create a work environment with features related with infotainment, also providing safety will be helpful on this task (Lau, 2013).

One of the solutions is bring more women for the truck market by one cab that provides her needs as safety, hygiene, oriented features and etc. Women could have an interesting role and feel interested in be in the haulage truck market. Companies like Volvo are deploying efforts in training women for being truck driver (Global News, 2012).

Technology: One of the most important trends related with technology is the conception of Driving Automation. Using the definition from the U.S. Department of Transportation's National Highway Traffic Safety Administration (NHTSA): "Self-driving vehicles are those in which operation of the vehicle occurs without direct driver input to control the steering, acceleration, and braking and are designed so that the driver is not expected to constantly monitor the roadway while operating in self-driving mode." (Aldana, 2013).

Current this technology is divided in some levels defined by the SAE International's Standard J3016:

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	**No Automation**	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	**Driver Assistance**	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	**Partial Automation**	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	**Conditional Automation**	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	**High Automation**	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	**Full Automation**	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Figure 29 – SAE definition for autonomous driving (Level of automation, 2014)

The technology to deploy those levels has being developed, but our current level of driving automation is level 2 – Partial Automation.

Another type of function, that will be important for the trucking business, is "platooning" which means that trucks drive close to each other to save fuel. The first truck is driven manually and the followers are automatic (with a driver inside) (Eutruckplatooning.com, 2016). Sometimes platooning can also mean the followers steer their trucks but have automatic regulation of longitudinal position. To achieve safe and close following, communication between the trucks involved in a platooning arrange will be needed.

Using the first set of customer needs provided by Volvo, was constructed the Table 6 to related the new trends and how the customer needs will be influence for the trends (phase 3 – see Figure 15).

Table 6 – Customer needs and trends implications

Needs	Implications
Hygiene - Proper toilets and sinks	• In future there will be a steady rise in women truck drivers. They will not find it convenient to do their personal things in open space outside the cab • As efforts are being carried to attract more young drivers in future. Younger generations will not prefer this kind of situation
Space - Fitness system and training	• Due to continuous long driving over a long time, the drivers might face stress and other health issues. Dedicating some amount of time everyday could help to alleviate this situation. Young generation will require this kind of system,

	one time that they take care about healthy.
Comfort - Bunk	• Due to increasing shortage of truck drivers, in some regions will be common have only one driver in each cab, therefore only one bed is necessary. • In other hand the driver shortage is leading for a recruitment of Eastern European drivers, who share the cab with a co-drivers, still using double bed solution
Comfort - Swiveling seats	• Swiveling driver seats will be of use for the platooning future. If the truck is under platooning link it is not necessary for the driver to have their hands on the steering wheel but he should be in the seat as per legislation. This will create some space for the driver where he can do some of his leisure activities like reading, while at the same time he can take control of the truck immediately if needed.
Have fun & socialize - Divide between work and leisure time	• There is a need for space between the driver's leisure and work space. When the drivers are at truck stops they like to have interaction with other drivers and some social activities like playing cards etc. For these kinds of activities they prefer to have space inside the truck and an electronic support for infotainment.

These processes combined with the Volvo specialists' interview were used as base to understand the customers and their needs.

4.2.1.2 Interviews

It was conducted a discussion with six experts from cross functional domain within Volvo Trucks. Three experts from the ergonomic department, one expert from product planning department and one expert from vehicle testing department were consulted and interviewed.

The main purpose of this discussion was to gain knowledge about different features incorporated in the living area of FH trucks and their respective constraints. It was also useful for us to elicit their current research on developing the living area in FH trucks. The discussion started with a short presentation containing some of the futuristic concepts from the competitors' concepts, which have semi-autonomous systems and some trends in platooning technology. This gave them an insight in what we are looking into. Since we are international students the discussion happened in English, so that everyone can understand.

What we infer from the inputs given by the experts was there are different trends prevailing within the western European drivers and eastern European drivers. There are some specific needs which differ between the drivers from two different regions. But majorly both of them share many common needs and expectations. We also inferred that the women truck drivers are increasing at a steady rate, where there is a need to develop better and more safer living area inside the cab. These kinds of inputs helped us to keep our design freedom as large as possible.

Information regarding the current profile of customer, problems faced in the current truck and reports from surveys done in the Europe was presented for us.

Many experts gave inputs regarding the trends prevailing in the trucking industry pertaining to the living area in the cab.

For example one of the experts explained about the swivel mechanism in the driver seat. This trend could create some space for the driver when the truck is under platooning link.

Contributions on the comfort in the sleeping bunks were received. When it comes to sleeping, the drivers require a good amount of sleep in order to stay fresh and awake for the next day.

References from the technology available inside the company that has been employed in the current developments was briefly explained, showing trends in new technologies and the feasibility

4.2.1.3 Customer Profiles

After an interpretation of the future scenario and the expert interviews, the group selected as a possible year for implementation 2024, based on the scenario and trend analysis. Thus, customer profiles were generated, with the reasoning to be addressed in the concepts:

- **Young male drivers** (20 to 35 years old): The driver shortage is leading for a recruitment of new young drivers. Fleet owners have preference for these drivers' that they are low experienced, earning less. As profile and characteristics will present limited knowledge about the truck, doesn't know the routes, might share the cab with co-drivers, have facility in handle new technologies, have an organized work-environment is not a priority and might be easily distracted.

  Young male generation will appreciate human-machine systems and hi-tech gadgets, space or tools to keep healthy, storages for snacks and infotainment for leisure.

  The Figure 30 presents what this type of driver wants, need and does.

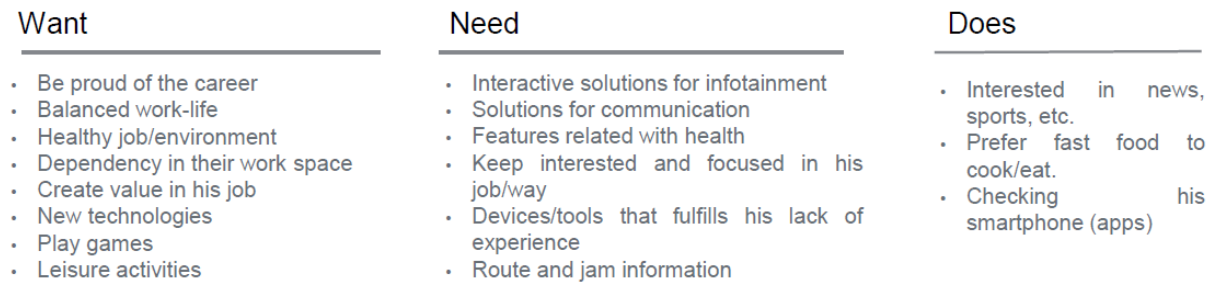


Figure 30 – Young male driver's characteristics

- **Young female drivers** (20 to 35 years old): By the same reasoning, drivers' shortage, women will be a labor force requested by fleet owners. Assuming the growth trend of

new technologies and the infrastructure support in the roads (truck-stops), women will feel interested and secure to work in this labor market. The incentive from truck-makers in terms of providing training for women, oriented solutions them or a specific advertising strategy might even influence this population. As characteristics young women will have limited experience, doesn't knowing the routes, facility in use new technological gadgets, healthy, have an organized interior cab is a priority and they are focused while driving.

As appreciated tools will requires human-machine systems and hi-tech gadgets, cook facilities and tools, storages, personal hygiene features and infotainment support for a connected life.

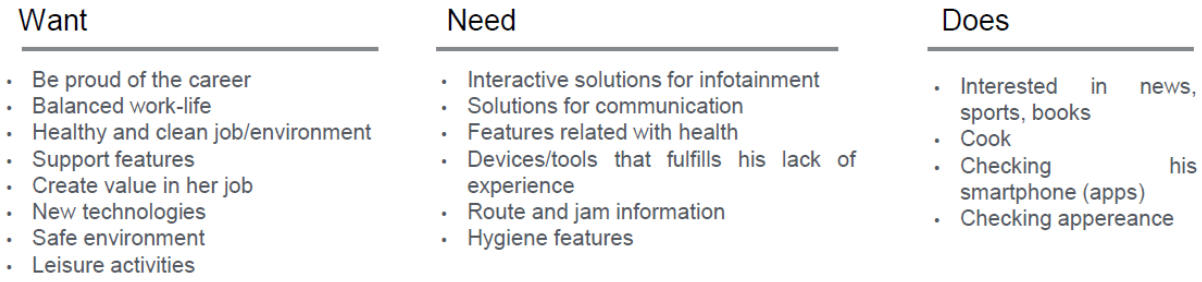


Figure 31: Young female driver's characteristics

- **Experienced drivers who share the cab** (35 to 55 years old): Considered high experienced drivers, these workers have different life-style, therefore need to be assume as a specific population still being a market for the FH-series. These drivers commonly travel with co-drivers during long periods (reaching up to 3 month each trip), are used to use solution provided by the parallel market. Are paid low by fleet owners and this is a reason to have more space in future long-haul truck market, adding the driver shortage trend. These truckers, commonly from the Eastern part of the Europe, are ill equipped but ready to perform small repairs in the truck, might present body pains due to a long period in this job, know the routes, as well as all the features and how to enhance the truck performance.

  These drivers will appreciate to have inside the truck a huge space for storages, facilities to cook (one time that prefer save money), area to socialize with co-drivers and tools that allows to talk with family, friends or employer. The Figure 32 presents some characteristics of this profile.

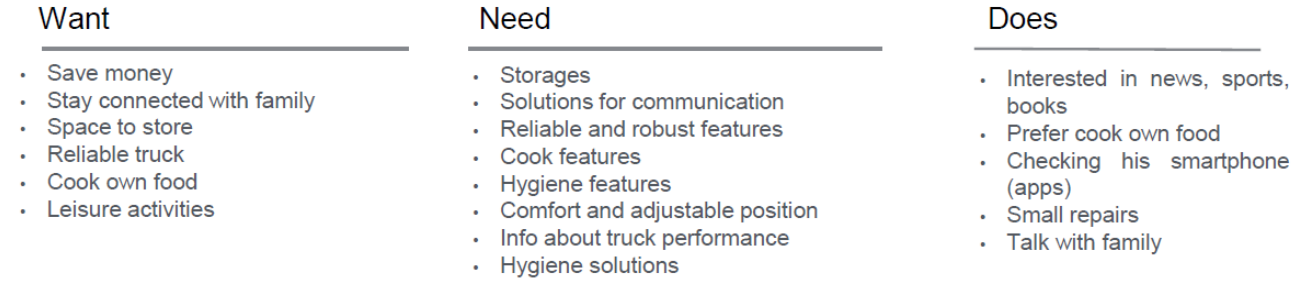


Figure 32: Drivers who share the cab characteristics

- **Experienced drivers who don’t share the cab** (35 to 55 years old): With a huge experience, these drivers are commonly from the western part of Europe use the interior cab of the FH in other way. Used to travel alone, during 5 days in a week away from home, prefer solutions for cab provided by the companies. Still being a market due to the necessity in transport high-valuable goods. Being able to perform a skilled work, receive higher salary. Is very sensitive about comfort and truck performance. Have some level body pain, preferring an organized environment.

  These driver request comfortable seats and bed, friendly human-machine interface, cook facilities, high-end features provided by the truck companies. The Figure 33 presents few characteristics of the profile.

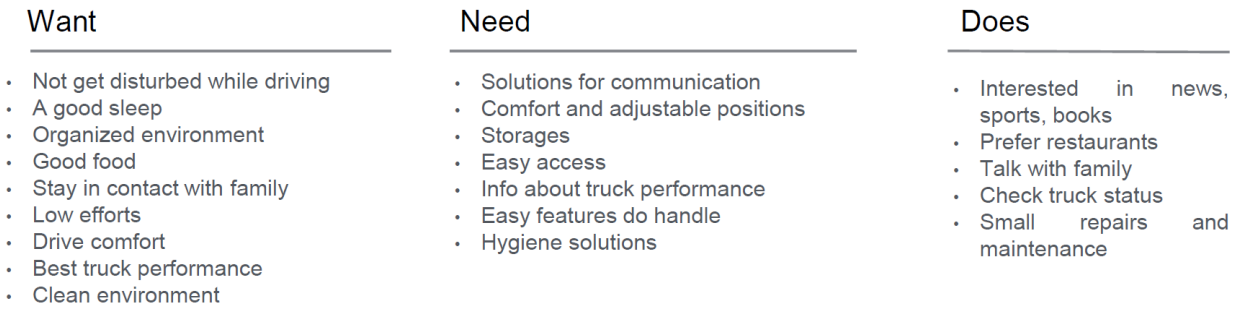


Figure 33: Drivers who don’t share the cab characteristics

Centered in this result, the customer needs were reviewed to reach the needs of customers in 2024.

4.2.1.4 Customer Needs

To define an appropriated set the customer needs, the group selected the demands that will grow in the next few years, using the interviews, forecasting the future and basing these needs in the profiles generated. The first set of needs provided by Volvo was edited.

The needs presented on the Figure 34 were selected assuming those that are shared by the four profiles. We selected the requirements that will benefit the drivers and fulfill the expectations of the consumers in the living area of truck.

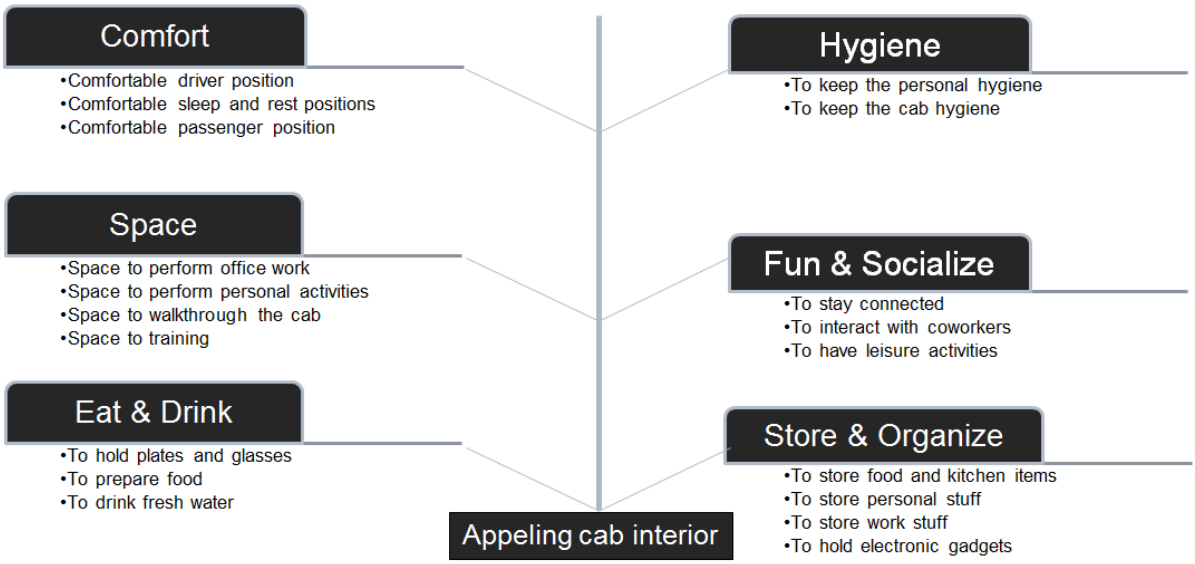


Figure 34: Future driver's needs

The needs that the concepts must fulfill have different level for each profile, but still the requirement on the roads that can be enjoyed by the whole population. The aim behind the selection is to achieve a higher number of customers.

With the customers identified and their needs, we were able to establish the target specifications.

4.2.2 Establish target specification

In order to establish the targets specified in the final list of requirement, the constraints and needs requested by the drivers were added. The demands were divided into Requirements (R) and desires, where requirements are the requirements contemplated and desires are the requirements that could be contemplated.

The requirements specified in "Features performance criteria" are the requirements that describe the feature directly perceived by the drivers while using specific equipment in an activity. They are linked with the refined customer needs.

The Appendix B illustrates the complete list of requirements, target values and the reasoning to address each question. There is a co

However, to cover the project scope, some requirements were selected. Is possible to see them on the Appendix B

The reasoning behind not choosing the complete list of requirements is due to the scope of the project and the maturity of the concept. Some of the requirements are checked or achieved in the last loop of development or after a product design phase. As the scope of the project isn't related with that, these requirements were excluded.

4.2.3 Generate product concepts

The aim of this phase is find the most suitable conceptual layout for the living area, including the features.

4.2.3.1 Function Means Tree

The function means tree was done in order to break down or decomposes the problem. The Appendix C presents the function means tree for the living area, where the black boxes describes the function and the red boxes describe the means to achieve the function.

This tool was helpful to evaluate and understand more about the usage of the living area. It was noted that the process must be divided in to layout generation and features generation, as explicated from the method. The layout level requirements describe the ergonomic assumptions. For features, the equipment that drivers use must be addressed in the layout.

4.2.3.2 Benchmarking

To inspire the ideation, a benchmarking was conducted in order to compare the products available in the long-haul market and the concepts developed by competitors. The aim is to search external sources for new ideas. The layouts and solutions from the competitors were also evaluated.

As source, we used the solutions developed by the companies, considering high-end versions. According to official sources the latest model trucks available in the market are Volvo – FH Series, Scania – R Series, Mercedes-Benz – Actros Series, Renault – Range T, DAF – XF Series, MAN – TGX Series and Iveco – Stralis Hi-Way. They were compared between categories related with the customer needs. The Appendix D present the result of the comparison, showing features and solutions provided for each need/category.

Physical inspection in these trucks was done in order to understand the usage and the feasibility of the competitor's vehicles. In order to feel the space inside the cab and play with the tools and interfaces provided by others truck-manufacturer, the solutions were mounted and dismounted, postures and positions were tried. The vehicles visited were Scania – R Series, Mercedes-Benz – Actros Series, Renault – Range T, DAF – XF Series, MAN – TGX Series and Iveco – Stralis Hi-Way and Hyundai – Xcient.

Assuming that the project is for a future truck, a benchmarking of the conceptual trucks was done based on the information shared by companies and presented in auto shows. The selected truck models include Freightliner Revolution, Walmart Advanced Vehicle Experience, Mercedes-Benz Future Truck 2025 and the Freightliner Inspiration Truck. Since these companies doesn't share enough information for a deep study, the approach and the categories selected for benchmark was the technological approach of each concept, the ergonomic aspects considered, the design aspects and what is the focus of each concept. In the Appendix E is presented the result of the benchmarking for future trucks in the long-haul market.

4.2.3.3 Layout concepts

From the brainstorming sessions held inside the wooden mock-up, making use of the foam boxes and layers, the following layouts were created:

> **NOTE:** In the concept pictures, the number 1 represents space for storage/features and 2 represents spaces for sleep, as decided in the methodology. In all concepts the front shelf was considered as space for storage/feature due to the constraints provided by Volvo – about microwave and radio position.

Concept 1: Single upper sleep area

Figure 35: Concept 1 – One upper sleep area

This concept is based on the future trends in the truck industry. Having only one space to sleep, this concept allows creation of more space for storage and walkthrough space inside the cab. With more space available on the floor, features that are currently neglected could be addressed in the living area. The space to sleep is positioned on the upper part of the cab rear wall. As consideration, the seats (driver and passenger) could be slided and swiveled in order to enjoy the lounge area that was created. More space to move inside the cab, space available to storage or to fit features, flexibility of the seats to move in different directions are considered advantageous. As a disadvantage, it has only one area to sleep and a top bunk that could be problem for old drivers. The personas/customer who would prefer this solution is the one who don't share the cab with co-drivers. They prefer to have more features provided by the company and an executive lounge area in the living space. Therefore these personas are mostly interested in this concept than young male and women young drivers.

Concept 2: Double sleep area - upper higher space

Figure 36: Concept 2 – Double bunk with upper higher space

This concept is based on the current truck layout, presenting a double sleeping area. One sleeping area situated at the lower end and another on the upper part of the rear wall. As differential in this concept, the idea is to create a mountable lower sleeping area. Therefore drivers could mount the second sleep area when sharing the truck with a co-driver. When not used this area could be used as a social area to be shared with co-drivers or to perform common activities. Spaces dedicated for storages are distributed around the walls in order to fulfill the storage volume requirement. The main sleeping area is positioned on the upper end. Regarding seats both could be slided and swiveled in order to use the living area. The advantage in this concept is that provided social area can be enjoyed and can also be used as a support environment for current activities. As disadvantage, there is less space to implement new features, since these spaces have to be dedicated for storages. This will be preferable for driver who shares the cab, and this concept will fit the needs of all those who share the cab.

Concept 3: Single lower sleep area – Embedded frame

Figure 37: Concept 3 – One sleep area with embedded frame

This concept uses the micro small apartments as reference where storages are embedded in the walls. With a single sleep area, this provides huge space that could be dedicated for storages or features, beneath and above the lower bunk. The variable sleep space allows driver to have more space to walk inside the cab. Both seats could be slided back and forward and can swiveled, in order to reach different

areas when the truck is under some level of autonomous driving. The advantages are, there are more space for storages and features, have a lower bunk which provides an easy access, more walkthrough area to move inside (walk straight) and a dedicated space for sleep that doesn't need to be mounted. The disadvantages are, there is only one sleep area and the feeling of crowded due to a huge set of storage and features placed in the walls. This concept is oriented for a driver who doesn't share the truck.

Concept 4: Single lower sleep area – Area to work

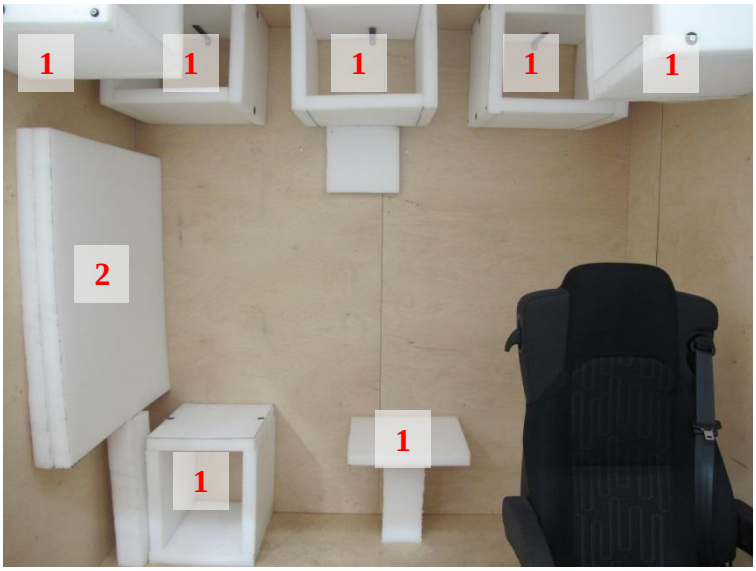


Figure 38: Concept 4 – One mountable sleep area

In this solution the development is based on a solution already provided by Volvo. A set of space dedicated for features or storages is located in the upper rear wall, with a mountable lower sleep area. The sleeping area in the lower part can be transformed to create a work environment allowing drivers to rest and relax in leisure time. This space could address features to cook and to eat inside the cab. As in the other concepts, both seats could be slided and swiveled. The work space is used. The advantage in this concept is the volume dedicated for storages or features and work environment created when space to sleep is disassembled. This concept addresses the needs of the driver who travels alone. Young female and male drivers prefer this concept, if more solutions are developed by the company.

Concept 5: Double sleep area – lower higher space

Figure 39: Concept 5 – Double sleep area with lower higher space

This concept is based on the current long-haul solution for double sleep area. Having a higher space for sleep at the lower part, storages and features are disposed on the floor and in the upper part of the wall. This concept provides sleep areas that doesn't involve assembling it. The storages on the floor are accessed by folding the sleep space towards the rear wall.

Both seats could be slided and swiveled. The lower bunk is considered the main sleeping area. Two sleeping places are considered as an advantage in this concept. As a disadvantage there is less space for drivers to interact, limiting the space usage. This concept addresses the need for cab sharing, when drivers travel with their co drivers. However the young generations are also contemplated and are more flexible to accept and live in proposed solutions.

Before the concept evaluation, an initial analysis was made using a morphological matrix in order to verify the feasibility of each layout features and solutions described as a need. This was done to improve the concept selection and take the decisions.

4.2.3.4 Features generation

In order to define what features will be comprised in this layout, morphological matrix was used. It provides a range of solutions and available possibilities.

4.2.3.4.1 Morphological Matrix

From the function means tree, the second level of functions was adopted to figure out ways to achieve the functions. The Appendix F presents the morphological matrix.

It is important to state that the morphological matrix cover the needs in terms of features, whereas the layouts cover the constraints and requirements related with ergonomics (the reasoning of split the generation).

Some of the solutions found were excluded for the combination in the concepts. The Table 7 presents those excluded and the reasoning behind exclusion.

The solutions that were excluded of the morphological matrix present a red dot (see Appendix F).

Table 7: Reasoning's for solutions exclusion

Comfortable sleep	Due to ergonomic aspects the hammock, sofa and sleep bag were excluded. As comfort is prioritized inside the company, these solutions don't satisfy the comfort level required for the FH.
Comfortable drive position	Bench is excluded due to the lack of comfort.
Comfortable rest position	During truck development, some tests are held. One of those is the crash-test, when the truck hit some barrier at set velocity. Ben bag could exit the truck when submitted to this test. Bench present lack of comfort for Volvo levels.
Fitness support inside cab	Due to the heavy weight of workout equipment's they are excluded. Weight compromise in the cab will decrease the weight that a truck can load respecting the regulations.
Cleaning support inside cab	Due to the reduced space, manual tools might be hard to handle inside the cab.
Personal support	Huge space for water reservoir and to install these features may increase

	the cab weight.
Food store support	Fridge may replace a thermal box and one cooler
Food prepare support	Oven and stove may present flammable risk into the cab, as well will require exhausting systems, commonly heavy. Kettle could be replace by the microwave.

4.2.4 Concept evaluation and selection

The concept evaluation was set to evaluate the concepts in terms of the ergonomic aspects and availability to fit features inside the cab.

Following the method, the Pugh matrix was applied in order to compare the concepts considering the requirements defined. The development team point of view was used to rank the concepts. Table 8 present the results of the evaluation.

Table 8: Pugh Matrix evaluation – developer's point of view scores

	Pugh Matrix Criteria		**Current FH**	**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**
Selection Criteria	Walkthrough area		0	+	+	0	+	+
	Body postures and clearances		0	+	0	-	+	+
	Space for straight walk		0	+	0	-	+	+
	Driver seat adjustments		0	+	+	+	+	+
	Passenger seat adjustment		0	+	0	0	0	0
	Passenger seat comfort		0	+	0	0	0	0
	Storages space availability		0	+	0	+	+	+
	Storages space access		0	0	0	+	+	+
	Bunk complexity		0	0	-	0	-	+
	Bunk accessibility		0	0	0	0	0	0
	Body clearance		0	+	0	-	0	0
	Availability for features		0	+	0	+	+	0
	$\sum_+$		0	9	2	4	7	6
	$\sum_-$		0	0	1	3	1	0
	$\sum 0$		11	3	8	5	4	4
	Total Scored			9	1	1	6	5

Was noted that the concept 1 is the best ranked, followed by the concepts 4 and 5. The Figure 40 exposes the ranking of the concepts.

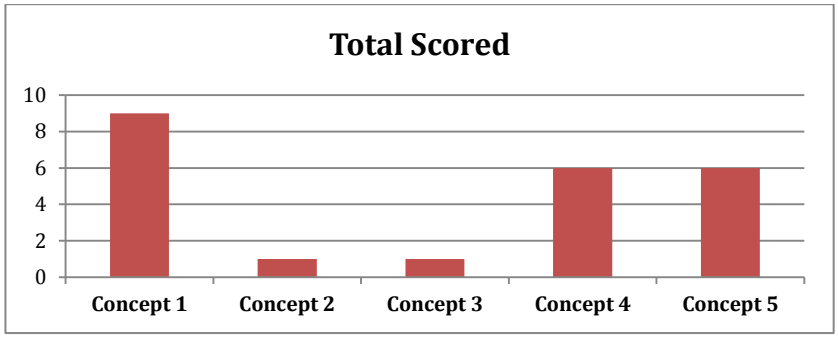


Figure 40: Concepts ranking

As the different profiles have different demands in a real scenario, the concepts will be ranked according to their needs. Taking this into account, we used one Pugh matrix for each person. The Appendix G presents the results from the Pugh matrix, considering how each persona evaluates the concepts, from their personal point of view.

However, after discussion with stakeholders, a decision with Volvo was made and the selected the concepts entered the System level design:

- Concept 1: As the best scored concept, was developed further.

- A new concept: Concept 5 emerged as the second best concept; however few modifications were required in the concept level before developing it further. Volvo always provides concepts with double bed but creating social place inside the cab was also their long time requirement. Hence from the generated concepts, concept 5 and concept 2 was merged together. This new concept has the benefit of double bed as well as the place to socialize inside the cab.

The final delivery is a pair of concepts, one with single bed (concept 1) and another with double bunk (new concept).

NOTE: Due to an agreement between Chalmers and Volvo only the double bunk concept is presented on this project.

4.3 System level design

In this phase, the results of the concepts selected and generated have the development improved, for a better visualization and understanding. Software's such as CATIA, DELMIA and VRED was used in order to design, evaluate and achieve a real environment conditions. Our system level design is briefly split up into three main sub phases like the product architecture, refinement of industrial design and concept testing.

4.3.1 Product Architecture

Before deciding the product architecture, a concept refinement was done. In the concept refinement stage merging of concepts happened to achieve feasible and efficient concepts.

4.3.1.1 Double Bunk concept

During the product architecture phase the concept 5 and concept 2 was combined to have effective and feasible solutions. Some of the characteristics and features were inherited from both the concepts and a new concept was made.

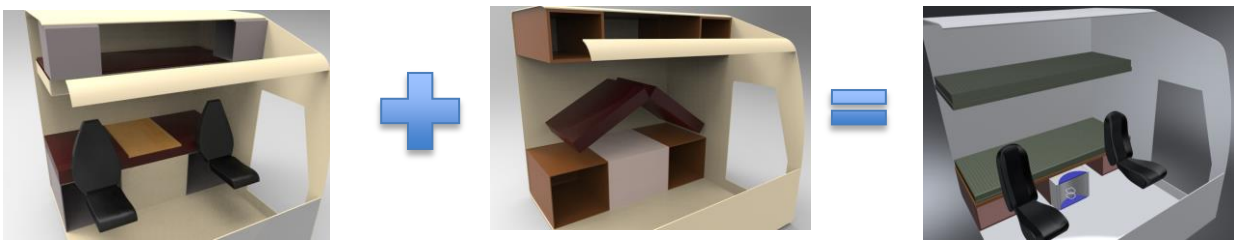


Figure 41: Concepts merged

In this phase some of the features from concept 5 were transferred to concept 2 to make it effective. One such feature or idea which was inherited to our double bunk concept was the single piece bunk. Initially in the concept 2 there was a mountable sleep area. In the Figure 41 there is a middle table in the lower bunk which was a separate part and the other part of the lower bunk was split into two pieces. After getting insights about the driver life style and his everyday life we decided to merge mountable sleep area into single piece lower bunk for ease of usage. We decided to retain the orientation and folding mechanism of the lower bunk and thus the double bunk concept evolved.

While designing the double bunk concept some features were taken into considerations for allocating the storages. The features like bed and refrigerators were taken into consideration as base for the development.

4.3.2 Industrial design refinement

In the industrial design refinement phase the double bunk concept was further refined by detailed designing to achieve the real environment. The Figure 42 and 43 illustrates the detailed design of the double bunk concept, showing a more matured model using CATIA.

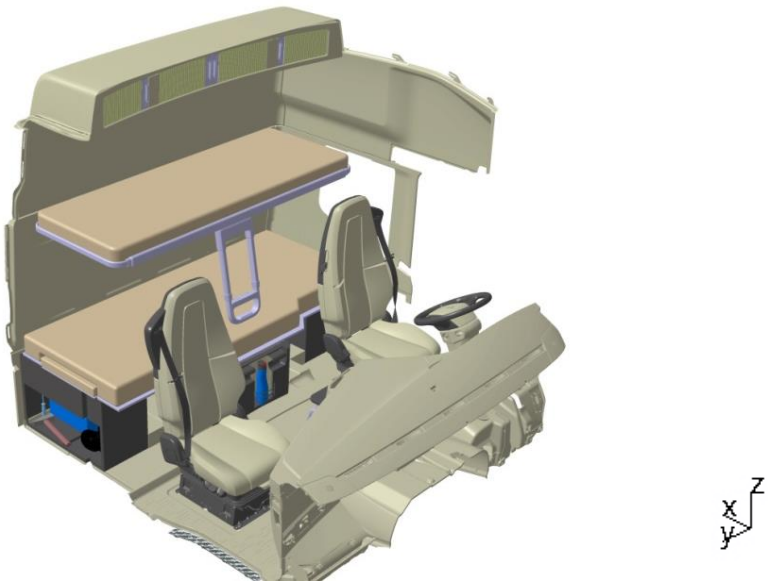


Figure 42: Double bunk concept

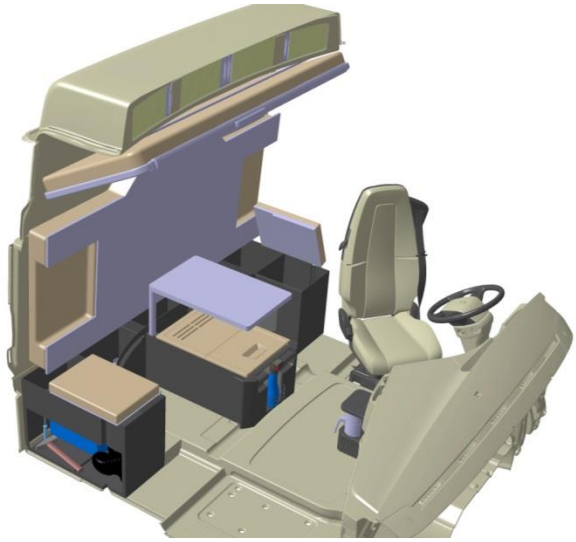


Figure 43: Double bunk concept with passenger seat hided

For the ease of visualization and understanding of concept we have hid some parts. The initiation of this phase started off by increasing the length of the cab in x direction to 300mm which was one of our design criteria's. This increase in length of the cab was achieved by editing the interior panels and floor panels of the Volvo FH-Series XHSL cab. This was done in order to achieve a realistic boundary condition for our concept to work. The Figure 44 illustrates the interior panels and floor of the Volvo FH series.

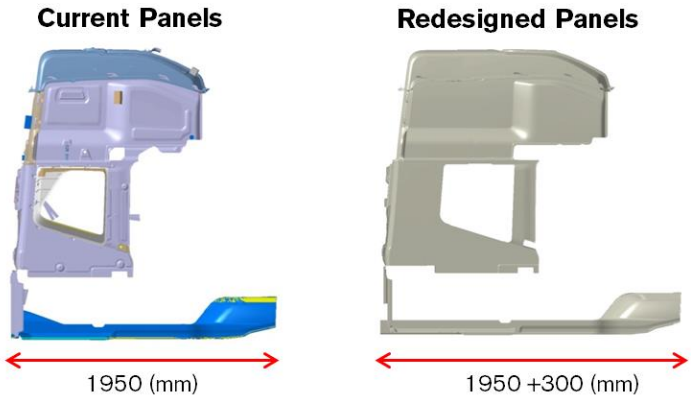


Figure 44: Volvo interior panels edited

The usage of our double bunk concept is explained in an effective manner in terms of customer needs and requirements. The category of needs and requirements which are addressed in this concept are comfort, fun and socialize, store & organize and eat and drink, hygiene and space. The final concept is presented below, through the customer needs.

4.3.2.1 Comfort

The comfort category in this concept describes about the driver and passenger seating positions and the sleeping bunk positions. The Figure 45 illustrates the driver and passenger seat positions inside the cab.

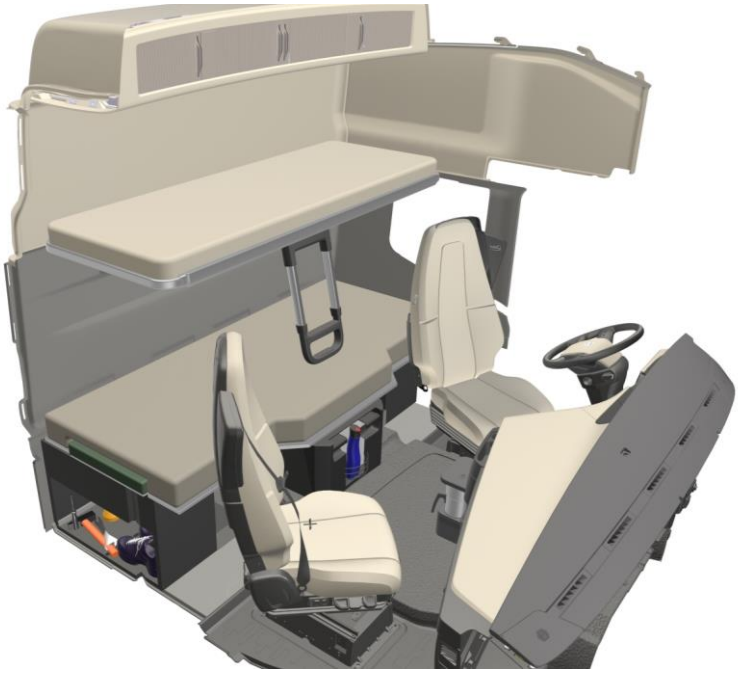


Figure 45: Seats swiveled

The main feature incorporated in the driver and passenger seat are that it can be swiveled to certain angle. The driver seat can be swiveled till 45deg and the passenger seat can be

swiveled till 45 and 90deg. Due to increasing level of autonomous driving, the legislations states that the driver should be attached with the seat. These angles makes driver to get control of the truck or intervene the system in a fraction of time. This is the reason behind why the driver seat in our concept can be swiveled till only 45deg. It is important to note that Volvo already offers solution with the passenger seat swivel, therefore this challenging to incorporate this solution in driver seat.

In our concept we have two beds to sleep with mattress. One bunk is located towards the lower part of the rear wall and the other bunk is located towards the upper part of the rear wall.

The dimension of the upper bunk is 700x1800x130 (mm) and could be folded partially towards the rear wall. The important feature of the upper bunk is that the height of the bunk could be adjusted. From the cab rear upper storage to the first position are 310 mm in Z direction (allowing the lower bunk be completely folded till the rear wall). The second height position is at 550 mm in Z direction (according to constraints provided for a comfortable space to sleep). The Figure 46 illustrates the upper bunk in our concept and its adjustability.

Both beds may be locked in the folded position using belts, as Volvo already offers this solution on the current FH-Series double bed.

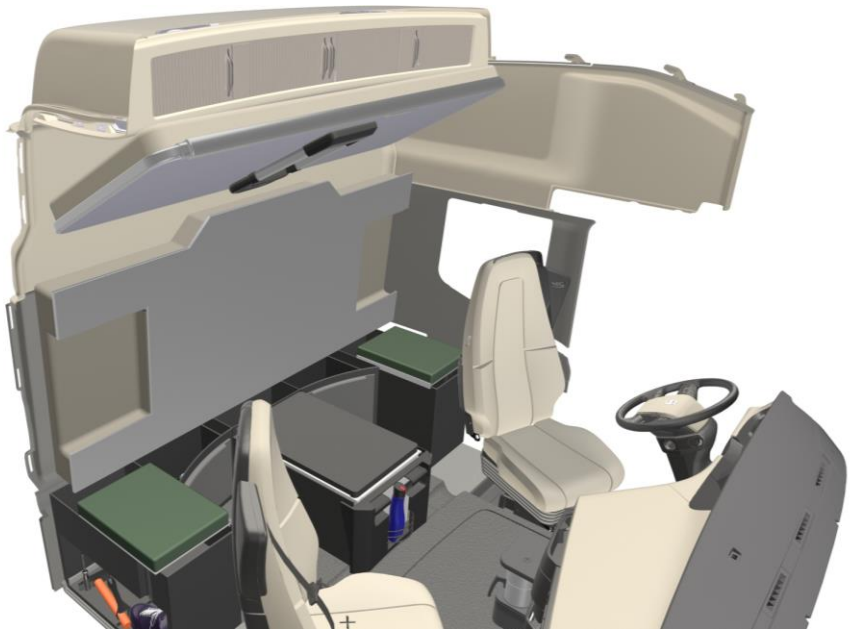


Figure 46: Bunks folded

There is a ladder present in the frame of the bunk in order to have easy access to the upper bunk for the drivers. This ladder is used in the current Volvo FH and may be folded below the upper bunk. The Figure 47 illustrates the ladder in the upper bunk.

Figure 47: Ladder with bunks in the sleep position

The dimension of the lower bunk is 900x2000x180 (mm). Similar to the upper bunk the lower bunk can also be folded towards the rear wall. A small portion - 40mm in x direction and 570 in y direction - of the lower bunk is cut on both the sides. This was done to facilitate the sliding of the driver as well as the passenger seat on the X direction. Regarding the bunk frame, the frame thickness chose was 30 mm, measurement near to what is used in the current vehicle). The Figure 46 and 47 illustrates the lower bed in our concept.

A portion of the lower bunk is split into two halves to create feature in the living area. This feature will be explained in the oncoming section.

4.3.2.2 Fun and Socialize

The fun and socialize category in this concept describes about the driver and passenger socializing area inside the cab. The Figure 48 illustrates the socializing area inside the cab.

As discussed in the comfort category, the reason behind the bunk split will be explained in this chapter. A small portion of the lower bunk is split into halves in order to create a sofa which serves as a socializing area or an area to work.

The portion of the lower bunk is cut horizontally not vertically. This was done keeping in mind about the ergonomic comfort for the drivers. If there are split lines on the bunk, the driver feels discomfort while sleeping or taking rest. To avoid these split lines the portion of bunk is split horizontally, in the mattress-frame interface.

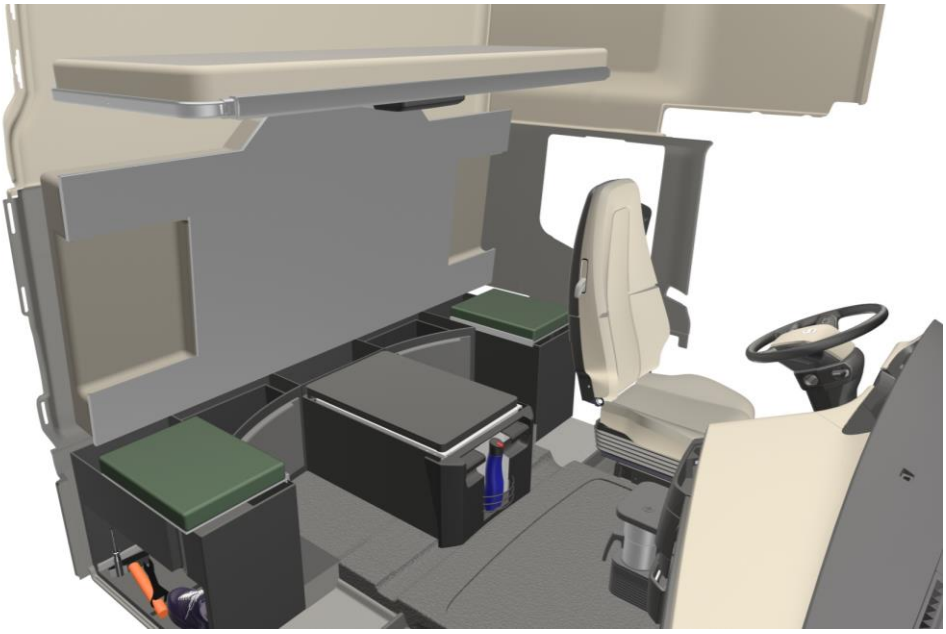


Figure 48: Social area

The total thickness of the mattress is 130mm. It is split into equal halves with 65mm sharing for both the bed and sofa. In order to have access the sofa, the lower bunk must be folded towards the rear wall and the upper bunk should be adjusted to have enough head room.

4.3.2.3 Store and organize

The store and organize category describes about the refrigerator and the storages in this concept. There are different types of storages present in this concept. The refrigerator is located in the center below the lower bunk. The driver and the passenger can access the refrigerator by sliding 490 mm towards front in X direction. There is a lid on the top of the refrigerator in which things can be stored and accessed. The Figure 49 illustrates the refrigerator in our concept.

Figure 49: Refrigerator and coffee machine detail

There is storage present on the floor of extreme left and right ends (W: 350 x L: 700 x H: 480 mm). These storages can be accessed both internally and externally and are split in to upper and lower compartments. The upper compartment can be accessed internally and the lower compartment should be accessed externally. To have the feeling of space and to visualize things, we have added few things in the exterior storage. The Figure 50 illustrates the exterior and interior storages.

The storage height follows the current FH-Series, providing the same height for access and sleep on the lower bunk.

One of the interior compartments on the set of storages may be dedicated to store valuable stuff, creating a door with locker for that. This allows the company to offer a safety box as an optional for the customer.

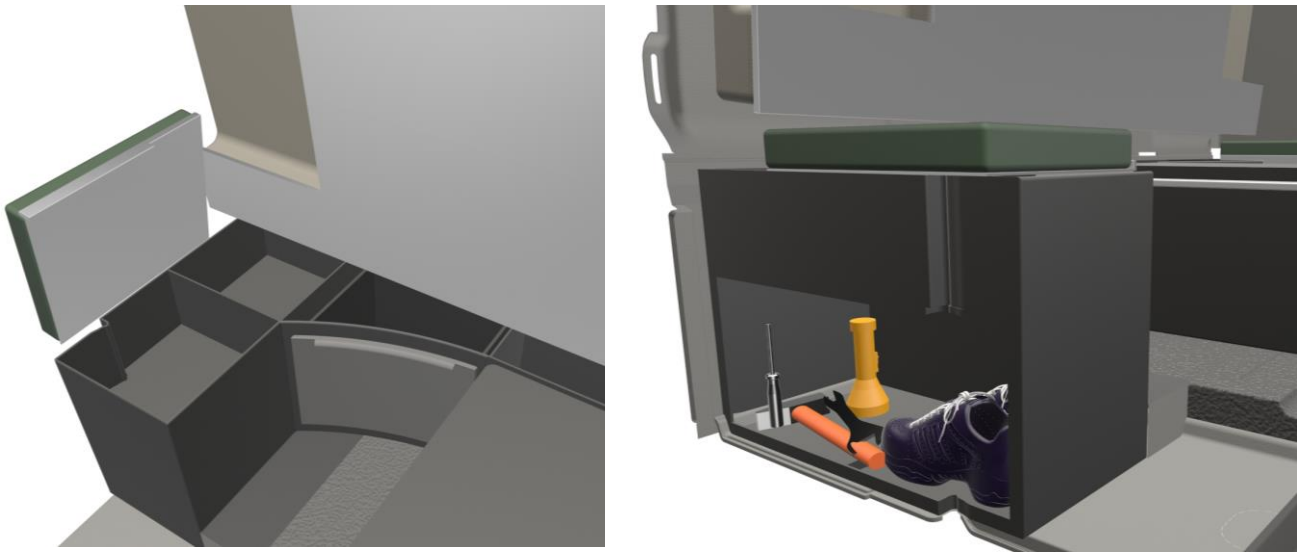


Figure 50: Side storages – interior and exterior access

There is a drawer present on the floor panel. This drawer could be accessed by sliding in X direction. The main purpose of this drawer is to increase the visibility while accessing the things inside this storage. The Figure 51 shows the drawer in this concept.

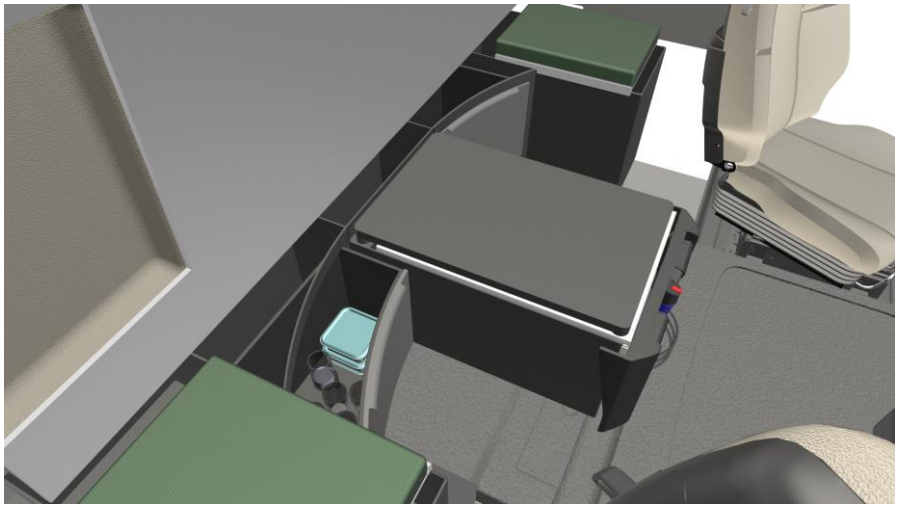


Figure 51: Drawer slide - detailed

The upper windshield was dedicated to storages, using the current application for this area.

In the upper rear wall, there is a set of storage. This solution is already provided by Volvo and it fulfills the ergonomic requirements as well.

To achieve the volume requirement, a net solution is proposed to adapt the upper bunk as storages. This allows drivers to store things when the upper bunk is not used.

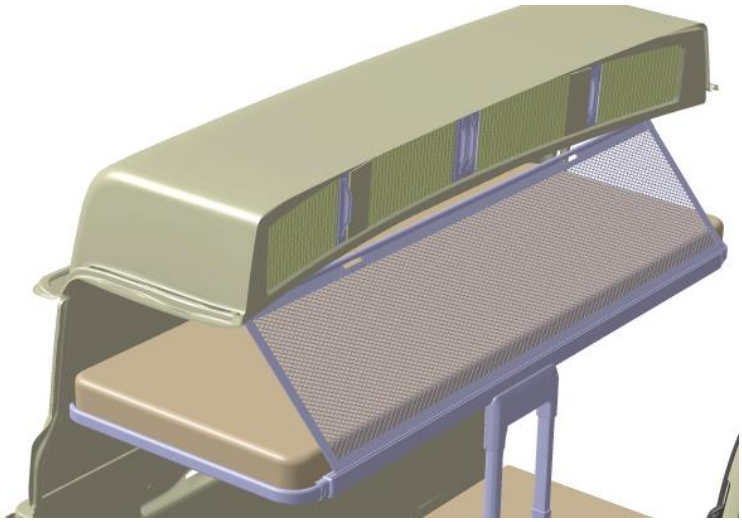


Figure 52: Upper bunk net

4.3.2.4 Eat and drink

The Eat and drink category describes about the holders and supports for eating and drinking in the cab.

There is a table embedded on the refrigerator console. This table can be accessed by folding the lower bunk towards the rear wall. The Figure 53 illustrates the table in our concept

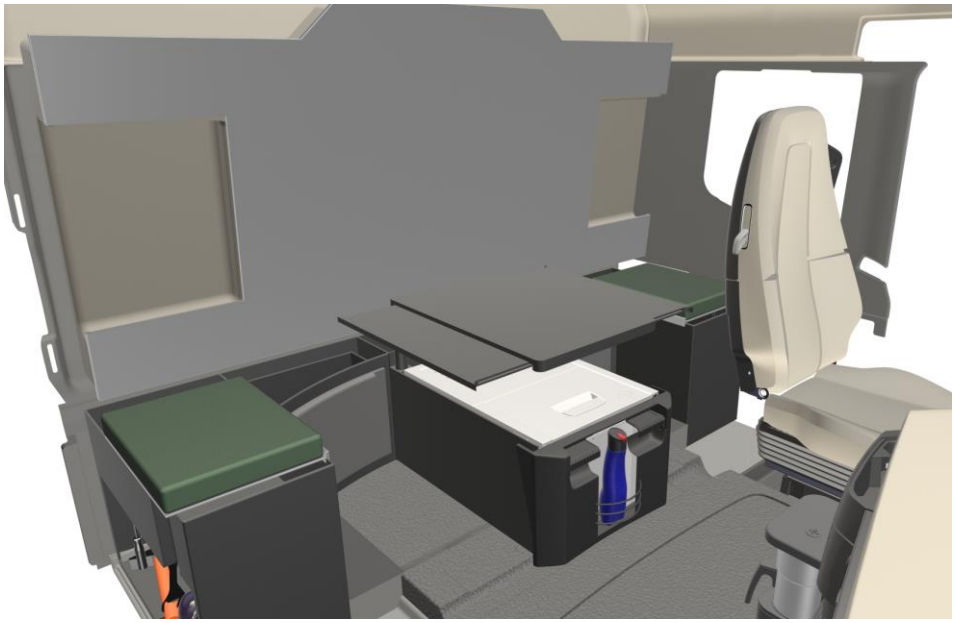


Figure 53: Center table for different activities

The table can be accessed by adjusting it in Z direction. The table is supported on one main frame. It has two sliding parts which can be extended out to increase the comfort. The table can be actuated either manually or through electrical actuation. The adjustable height of the table allow set the table for an ergonomic position.

To have a fresh water near the driver seat, it is proposed that a water console is embedded to the fridge with a holder (see Figure 49), allowing the driver to have fresh water while driving.

A coffee machine may be attached to the center part of the dashboard (see Figure 49), providing reachable coffee while driving.

A microwave is located on the upper front storage, as recommended by the Volvo (see Appendix B). The Figure 54 shows the microwave location.

Figure 54: Microwave position

4.3.2.5 Space

This category describes about the interfaces that drivers will have on the truck.

The Space inside the cab is presented and evaluated through the DELMIA analysis. This evaluation presents the main postures and clearances between the driver and the environment, as well the accessibility. This section is explained in the ergonomic evaluations chapter.

4.3.2.6 Hygiene

The hygiene describes about the features and solutions for personal and cab hygiene.

This concept is mainly oriented for drivers who shares the cab and are away from home for many days. Therefore, the need for storing stuffs like (food, cloths, tools, etc.) is more important than the space that could be used for personal hygiene solutions (toilets, sinks, etc.). Consequently, personal hygiene solutions were not designed.

For cab cleaning, it was decided that Volvo might provide portable electrical tools like vacuum cleaner. Waste bins might be placed on the dashboard, as Volvo offers in the current truck.

4.3.3 Ergonomic test product concept

In order to determine the areas of accessibility and to refine the concept development phase, the ergonomic evaluations were done for our final concept. The ergonomic evaluation was done in DELMIA software using Human activity analysis. Human Activities Analysis specifically focuses on how a human will interact with objects in a working environment, as well as the effects of lifting, lowering, pushing, pulling and carrying on task performance.

Human Activity Analysis is part of the DS DELMIA human modeling solution that also includes Human Builder, Human Posture Analysis, Human Measurement Editor, Human task simulation.

Under human activity analysis in DELMIA there are five main types of analysis. They are

- RULA (Rapid Upper Limb Assessment) analysis.
- Lift – Lower analysis
- Push – Pull analysis
- Carry analysis
- Biomechanics single action analysis

As a part of scope of our project we have evaluated the ergonomic feasibility using RULA analysis.

The RULA analysis was developed to investigate the exposure of individual workers to risks associated with work-related upper limb disorders. RULA analysis gives the maximum and minimum risks factors in our body.

These risk factors generally have scores ranging from 1 to 7. All these risk factors above combine to give a final score ranging from 1 to 7. Each of these score range has some colors and all these colors indicate the level of acceptance of posture.

- 1 and 2: (Green) indicates that the posture is acceptable if it is not maintained or repeated for long periods of time.
- 3 and 4: (Yellow) Indicates that further investigation is needed and changes may be required.
- 5 and 6: (Orange) indicates that investigation and changes are required soon.
- 7: (Red) indicates that investigation and changes are required immediately.

The Figure 55 illustrates the RULA analysis table which has postural scores for different segments in our body.

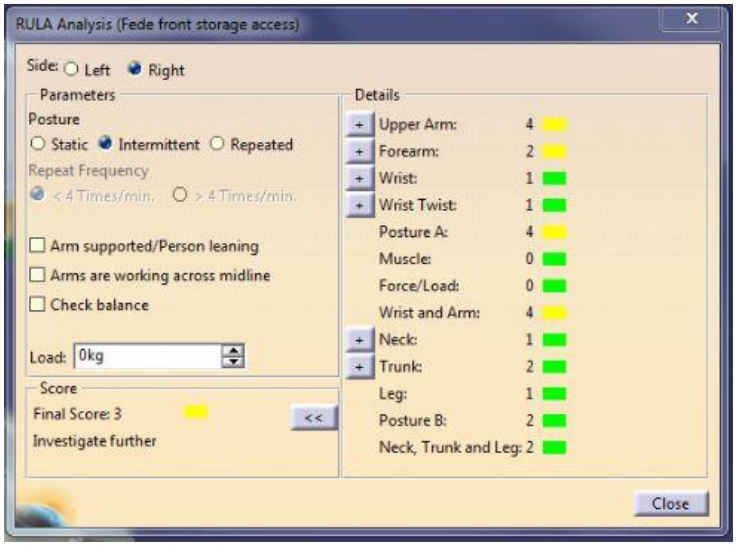


Figure 55: RULA analysis example

In order to perform ergonomic evaluation for our concept, manikins with different percentiles were selected.

The manikin percentiles considered for our concepts were Male 99%, Male 50%, Female 50% and Female 5%. These percentiles represent the personas considered in the concept generation phase.

For ergonomic evaluations of our concept, some important postures were evaluated to determine the ergonomic feasibility and the human accessibility. In our final concept it was achieved through manikins. Some of the postures of manikin considered for interior analysis were:

- Refrigerator access from the driver seat.
- Lower storage access.
- Drawer access.
- Sofa and Table access.
- Upper rear shelves access.
- Upper front shelves access.

For illustrative purpose we have images of the 99% German male population, however in the graphs and tables are possible to see the evaluations for rest of our percentiles.

4.3.3.1 Refrigerator access from the driver seat

The access to the refrigerator from the driver seat was evaluated using 99% of the German male population. The reference point considered for this manikin percentile is the H Point reference. The Figure 56 illustrates the manikin accessing the refrigerator from the driver seat.

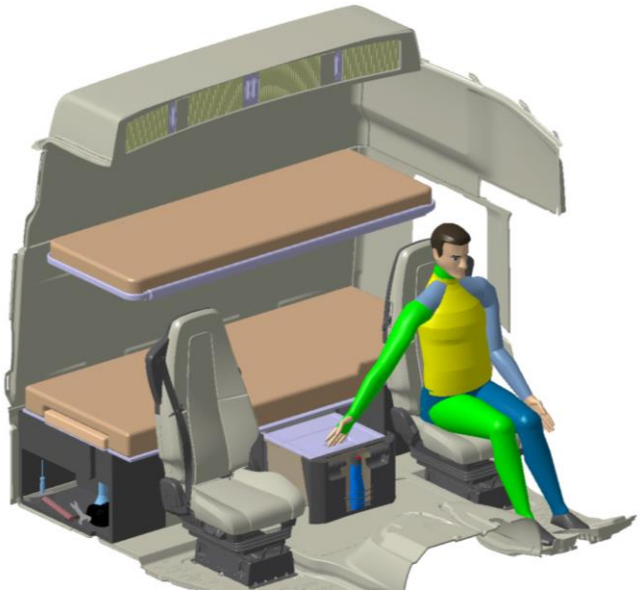


Figure 56: 99% German percentile accessing the refrigerator

In the figure, the manikin is trying to access the refrigerator from the driver seat by sliding in X direction. The colors in the manikin body represent the scores for each body segment from the RULA analysis as stated previously. The final postural score from evaluation of all the risk factors is 3 (yellow), which is a good acceptance level. The Table 9 illustrates the postural scores at different segments in the manikin for different percentile population. From this table some interpretations were done.

Table 9: Manikins postural scores for refrigerator access

Human Percentile	Postural Scores							
	Upper Arm	Fore Arm	Wrist	Wrist Twist	Wrist and Arm	Neck	Trunk	Leg
99% German Male	2	2	2	1	3	1	3	1
50% German Male	2	2	2	1	3	1	3	1
50% German Female	2	2	2	1	3	1	3	1
5% German Female	3	2	2	1	4	1	3	1

The Figure 57 presents the scores for each body part disposed in a graph for the refrigerator access.

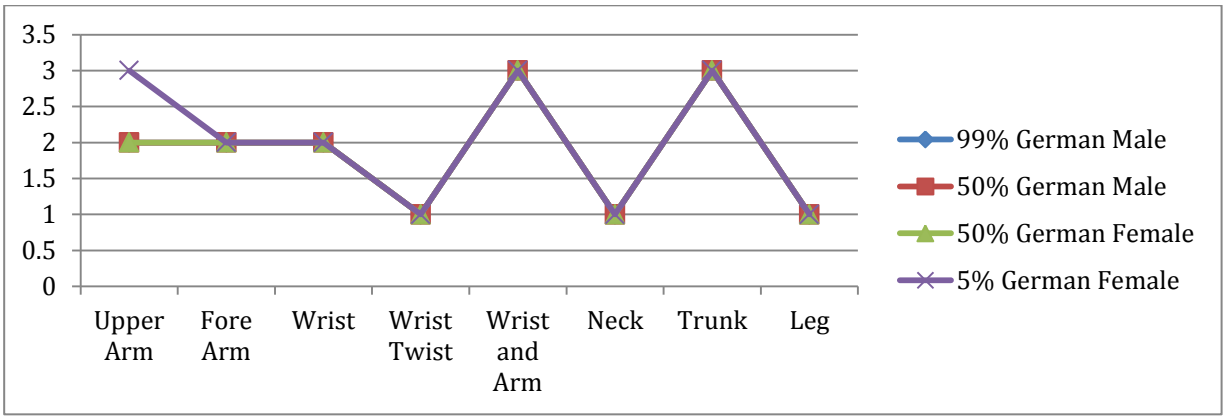


Figure 57: Scores graph for the refrigerator access

From the above graph and table we interpreted that all the percentiles have same postural scores except for 5% German female population. Since they are the smallest compared to all other population they have a little discomfort when accessing the refrigerator.

4.3.3.2 Lower Storage access

The access to the lower storage was evaluated using 99% German male population. The reference point considered for this manikin is between the legs, since he will be standing on the floor while accessing the lower storage. The Figure 58 illustrates the manikin accessing the lower storage.

Figure 58: 99% German percentile accessing lower storage

In the figure, the manikin is trying to access the lower storage by squatting and leaning forward. The colors in the manikin body represent the scores for each body segment from the RULA analysis as stated previously. The RULA analysis was done for other percentile population as well. The Table 10 illustrates the postural scores at different segments in the manikin for different percentile population. From this table some interpretations were done.

Table 10: Manikins postural scores for lower storage access

Human Percentile	Postural Scores							
	Upper Arm	Fore Arm	Wrist	Wrist Twist	Wrist and Arm	Neck	Trunk	Leg
99% German Male	3	2	2	1	4	1	3	1
50% German Male	3	2	2	1	4	1	3	1
50% German Female	3	2	2	1	4	1	3	1
5% German Female	3	2	2	1	4	1	3	1

The Figure 59 presents the scores for each body part disposed in a graph for the lower storage access.

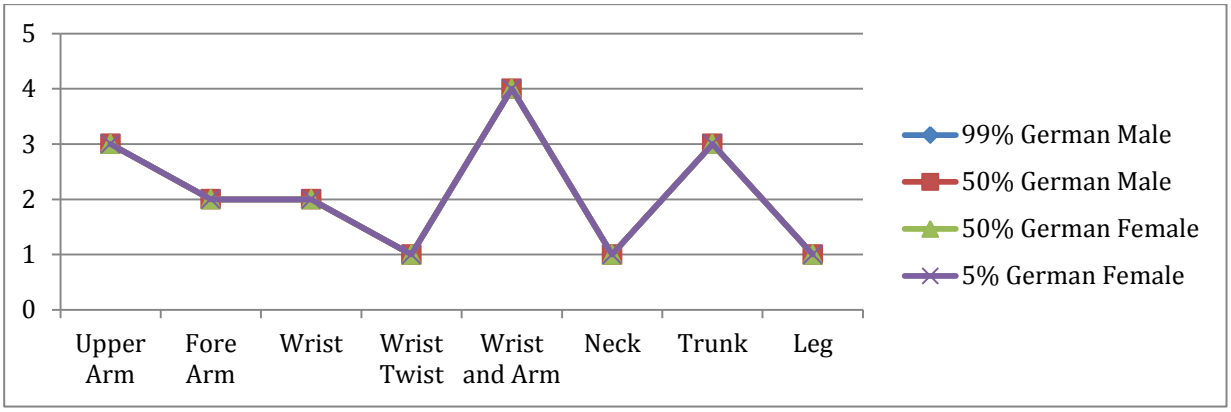


Figure 59: Scores graph for the lower storage access

From the above table and graph we found that all percentile population has same level of postural score in accessing the lower storage.

4.3.3.3 Drawer Access

The access to the drawer was evaluated using 99% German male population. The reference point considered for this manikin is between the legs, since he will be standing on the floor between the fridge and the sofa while accessing the drawer. The Figure 60 illustrates the manikin accessing the drawer.

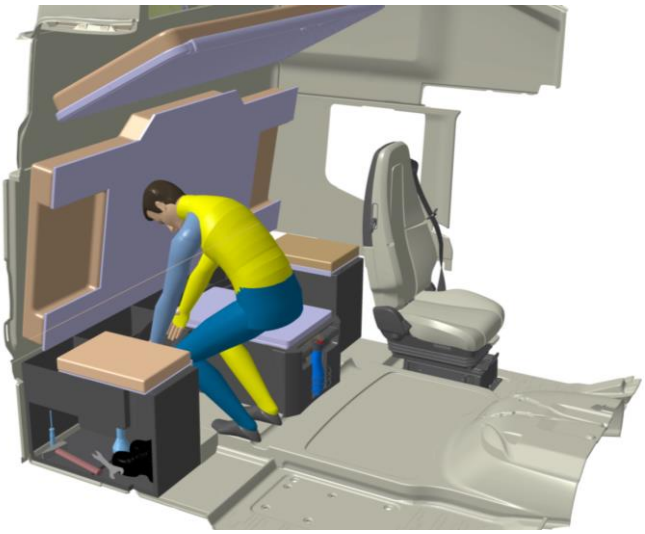


Figure 60: 99% German percentile accessing drawer

In the figure, the manikin is trying to access the drawer between the sofa and the fridge by squatting and leaning forward. The colors in the manikin body represent the scores for each body segment from the RULA analysis as stated previously. The RULA analysis was done for other percentile population as well. The Table 11 illustrates the postural scores at different segments in the manikin for different percentile population. From this table some interpretations were done.

Table 11: Manikins postural scores for the drawer access

Human Percentile	Postural Scores							
	Upper Arm	Fore Arm	Wrist	Wrist Twist	Wrist and Arm	Neck	Trunk	Leg
99% German Male	4	2	2	1	4	1	3	1
50% German Male	4	2	2	1	4	1	3	1
50% German Female	4	2	2	1	4	1	3	1
5% German Female	4	2	2	1	4	1	3	1

The Figure 61 presents the scores for each body part disposed in a graph for the drawer access.

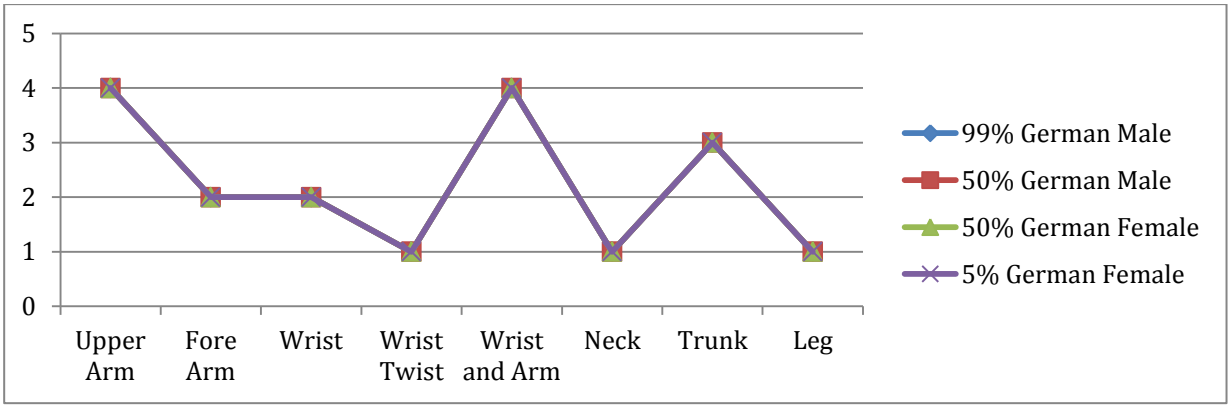


Figure 61: Scores graph for the lower the drawer access

From the above table and graph we found that all percentile population has same level of postural score in accessing the drawer.

4.3.3.4 Sofa and Table access

The access to the Sofa and table was evaluated using 99% German male population. The reference point considered for this manikin is between the legs, since he will be walking towards the sofa to access it. The Figure 62 illustrates the manikin seated in the sofa and accessing the table.

In the figure the manikin is seated on sofa and accessing the table by leaning forward. In order to access the sofa, the lower and the upper bunk should be completely and partially folded respectively as shown in figure. The color segments in the body represent the RULA analysis as stated previously. The Table 12 illustrates the postural scores at different segments in the manikin for different percentile population.

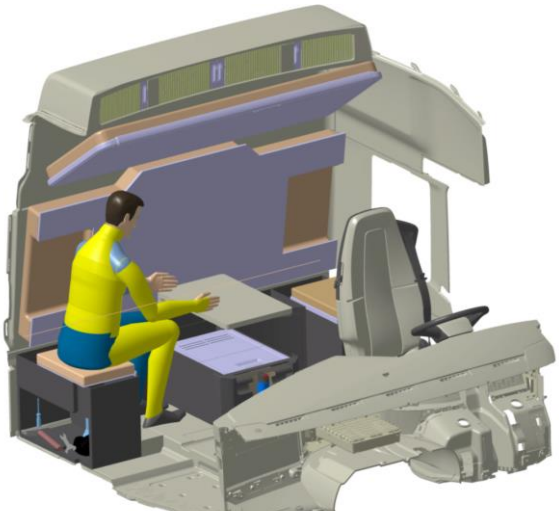


Figure 62: 99% German percentile accessing sofa & table

Table 12: Manikins postural scores for sofa and table access

Human Percentile	Postural Scores							
	Upper Arm	Fore Arm	Wrist	Wrist Twist	Wrist and Arm	Neck	Trunk	Leg
99% German Male	3	2	2	1	4	1	3	1
50% German Male	3	1	2	1	4	1	3	1
50% German Female	3	1	2	1	4	1	3	1
5% German Female	3	1	2	1	4	1	3	1

The Figure 63 presents the scores for each body part disposed in a graph for the sofa and table access.

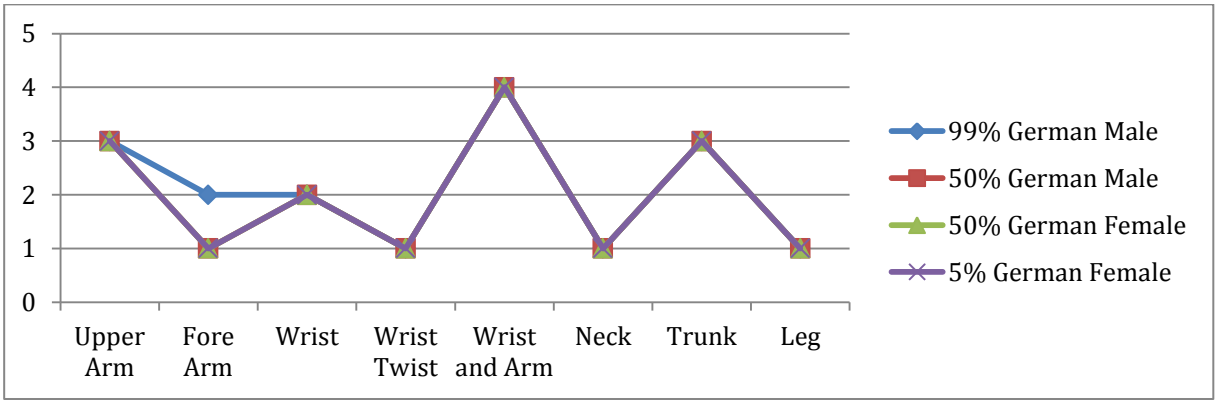


Figure 63: Scores graph for the sofa and table access

From the above table and graph we found that 99% of the German male population has little comfort on the forearm while seated on the sofa and accessing the table.

4.3.3.5 Upper Front Shelf access

The access to the upper Front shelf was evaluated using 99% German male population. The reference point for this manikin is also considered between the legs, since he should stand while accessing the upper front shelf. The Figure 64 illustrates the manikin accessing the upper front shelf.

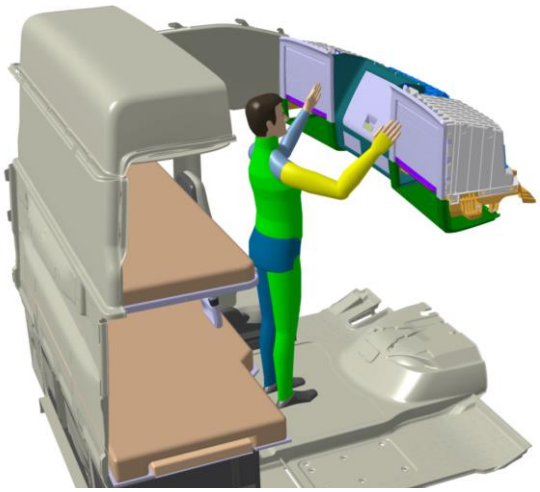


Figure 64: 99% German percentile accessing upper front storages

In the figure the manikin is standing on the floor and accessing the upper front shelf. The manikin should be able to access the storage on both the left and right hand side. The color segments in the body represent the RULA analysis as stated previously. The Table 13 illustrates the postural scores at different segments in the manikin for different percentile population.

Table 13: Manikins postural scores for upper front storage access

Human Percentile	Postural Scores							
	Upper Arm	Fore Arm	Wrist	Wrist Twist	Wrist and Arm	Neck	Trunk	Leg
99% German Male	4	2	1	1	4	1	2	1
50% German Male	4	1	1	1	4	1	2	1
50% German Female	4	1	1	1	4	1	2	1
5% German Female	4	2	1	1	4	1	2	1

The Figure 65 presents the scores for each body part disposed in a graph for the upper front storage access.

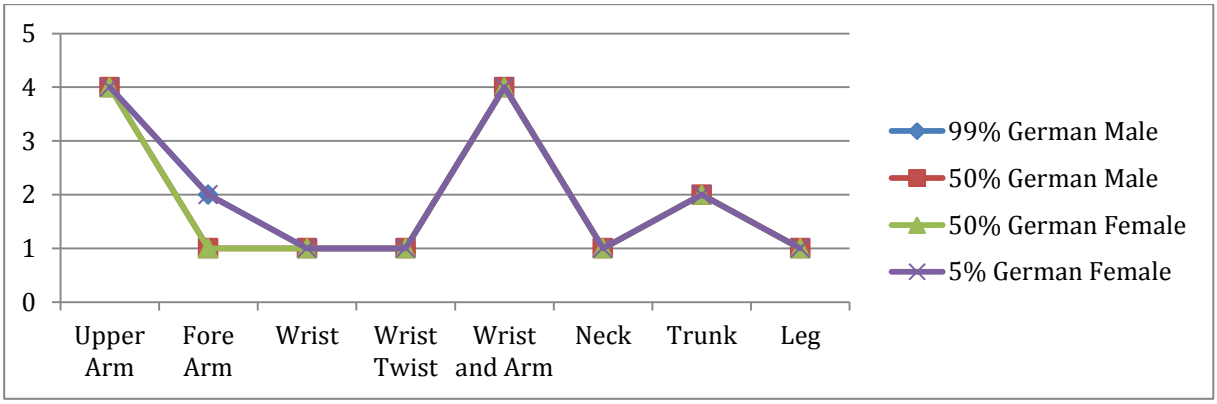


Figure 65: Scores graph for the upper front storage access

From the above graph and table we found that 5% German female population has little discomfort in forearm in reaching the upper front shelf.

4.3.3.6 Upper Bunk access

The access to the upper bunk was evaluated using 99% German male population. The reference point for this manikin is also considered between the legs, since he should stand while climbing up the ladder to access the upper bunk. The Figure 66 illustrates the manikin accessing the upper bunk.

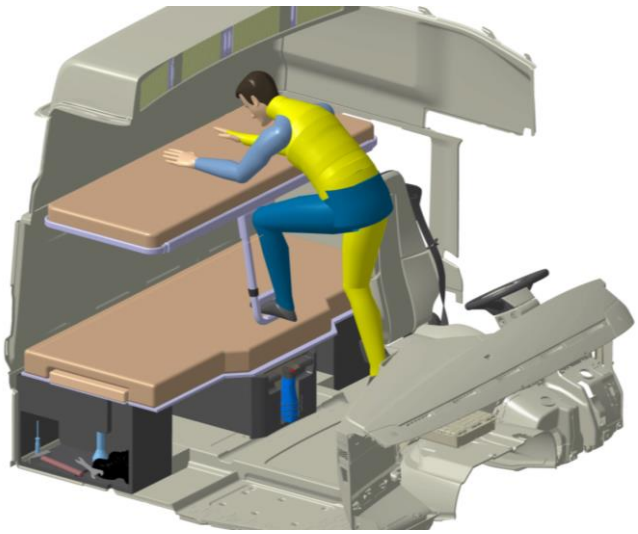


Figure 66: 99% German percentile accessing upper bunk

In the figure the manikin is climbing on the ladder with heads bent down. He is accessing the upper bunk. The manikin should be able to access the upper bunk with an acceptance level of head room. The color segments in the body represent the RULA analysis as stated previously. The Table 14 illustrates the postural scores at different segments in the manikin for different percentile population.

Table 14: Manikins postural scores for the upper bunk access

Human Percentile	Postural Scores							
	Upper Arm	Fore Arm	Wrist	Wrist Twist	Wrist and Arm	Neck	Trunk	Leg
99% German Male	4	2	2	1	4	1	3	1
50% German Male	4	2	2	1	4	1	3	1
50% German Female	4	2	2	1	4	1	3	1
5% German Female	4	2	2	1	4	1	3	1

The Figure 67 presents the scores for each body part disposed in a graph for the upper bunk access.

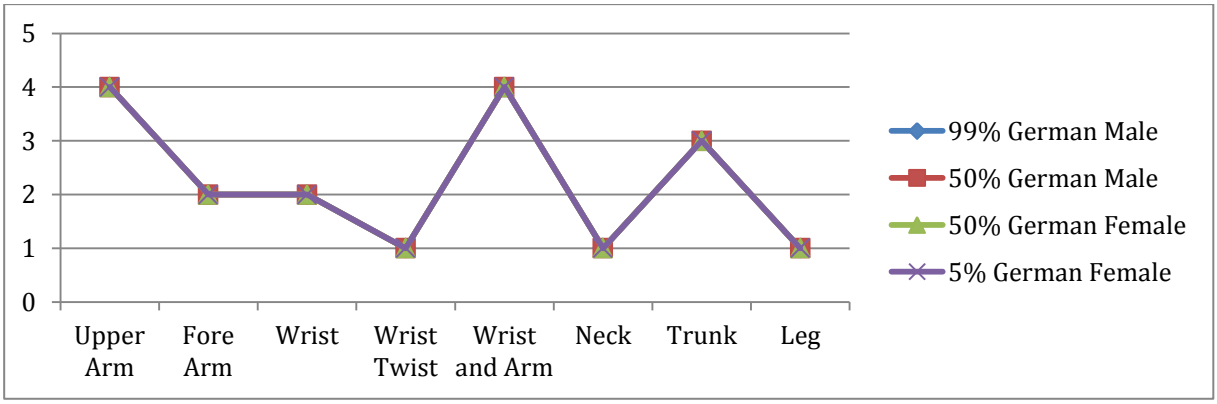


Figure 65: Scores graph for the upper bunk access

5. DISCUSSION

Initially when we were benchmarking the futuristic concept models offered by different companies, we noticed one common thing among all of them. Each company have their own segment of customers and their solutions where focused towards that. For example with the Walmart concept truck was focused on the powertrain module, while Mercedes was focused on the automated module. But one important fact is that each of them has their unique HMI (Human machine interaction) interface.

Basically to elicit the underlying needs of the customers, we had few internal discussions with different departments within Volvo. The quantitative approach of surveying did not work for us since it was hard to reach a large crowd in shorter duration. We are therefore satisfied with the method we have chosen, but the research would have been better if even more people were involved. The questions during the interview had a subjective approach and were a structured way. One thing we noticed during the research phase, minor needs have not been considered or addressed by many trucking companies. For example place for drivers to have their shoes inside cab, place to have their work clothes and gloves dry etc. These needs were also not addressed in this project since it was out of our scope.

During the initial phase of concept generation it was hard to create concepts because of more design constraints on a wider scope. This was solved by making use of the wooden mock up provided by the Volvo. The wooden mock up gave us a real feeling of the cab interior and feeling of space inside the cab. Hence this was useful for us to generate ideas. We followed one thumb rule right from the start of the concept generation phase. All the ideas and concepts should have practical feasibility and no purely conceptual ideas. With the valuable inputs from Volvo and findings by us, some feasible concepts were generated.

Our elimination of concepts was based on some criteria's. From the finding and discussions we found some practical problems in driver's day to day life. For example we can't propose them a bed solution which involves more time to assemble since many drivers don't prefer that. So these kinds of things were taken into consideration and our eliminations were based on this. In this phase not all practical situations were considered like cab tilt and extreme dynamic conditions.

Although we are satisfied with the final results, what's important not to forget is that we wanted to showcase the layout possibilities and features inside the cab rather than a detailed product design. If detailed product design would have been considered however, this project would have taken much longer than six months and the complexity level would have increased significantly. The important note is that the final concept was showcased in actual Volvo FH interior panels. It was also designed respecting the current ergonomic requirements of the Volvo.

The difficulty we faced mostly during the project was the task to stay objective and apply the methodology taught from school. This made it hard initially for us since there were so many

ways we could choose, but with time and knowledge increasing, we felt satisfied with the methods chosen and modifications made. The thing which we noticed understood that the design is always meant for the user and the customer. We both learnt that we should always have a track of it during the entire course of the project.

6. CONCLUSION

We have proposed a new interior solution for the next generation FH trucks which has enhanced features like increased storage space and bunk length. We also created a new space to socialize inside the cab. This new interior solution has a good market value which has been proven by addressing the needs and requirements of the present and the future drivers.

The solution to the new interior was approached by eliciting the needs and requirements of the drivers and analyzing the wide range of solutions available in the market. The initial phase started off by addressing who will be our customers and this led to creation of four different personas. Our needs and requirements were focused on these personas. The needs and requirements were elicited by analyzing the trend prevailing in the trucking industry and also having inputs and discussions from Volvo. The final set of needs was achieved by considering all the possible criteria like ergonomics, design and futuristic trends.

The wide range of solutions available in the market were analyzed by technological assessment and benchmarking the competitor trucks available in the market. From the benchmarking what we saw was currently all the long haul trucks in the market provide same level of layouts and features for interior solution despite unique product designs. From the technological assessment we noticed many innovative interior solutions have been offered by different industries like modular homes, aerospace and nautical industries.
These assessments and broad scope of our project enabled us to address various needs of the drivers which helped us to create different concepts. Considering the ergonomic requirements and practical feasibility the final concept was chosen.

The proposed solution fulfills the needs like comfort, fun and socializes, eat and drink, store and organize posed for the product. The new solution solves the ergonomic requirements and showed promising results which could be more appealing for the next generation truckers.

7. RECOMENDATIONS

We noticed there is a steady trend in the increasing level of automation within the trucking industry. This trend might create new grounds for innovative interior layouts. Since there is going to be increase in length of the cab dimensions research could be more focused towards having a flat floor inside the cab. This flat floor, i.e. no engine tunnel on the floor of the cab interior, could enhance many features inside the cab.

The needs and requirements are focused towards the present drivers. More research could be done to forecast the needs to the future young generation drivers because they could possibly be the primary customer in the future. Addressing their needs would create value for their work and makes them feel proud about their work.

The research could be more focused towards creating more infotainment system inside the cab. We noticed that in future many companies will have their unique HMI interfaces. The required information could be provided depending on who drives the truck. For example if an inexperienced driver is driving, he could get information regarding the most optimized route, fuel efficient driving and some entertainment stuffs. This information should differ if an experienced driver is driving the truck. Unique information like what kind of exercises should be done after 4 hours of driving could be provided by Volvo. Minimizing the usage of standard features available in the market creates a competitive edge through unique product differentiation. During our research we have noticed that even other segments such as the furniture market or home interiors where a lot of convenient and compact design can be an inspiration.

In our concept we have focused on creating the layout rather than the in-depth product designs but we had assumed axis for hinges and other parts. Detailed study is recommended to perfect the product. During the ergonomic evaluation of the concept we noticed that 50% male and female were not able to reach the rear upper shelf. We noticed that increase in length of the cab, has moved the shelf inwards which is impossible for shorter people to access it. Hence the length of the rear shelf should be optimized for increase in length of the cab.

8. REFERENCES

Aldana, K. (2013). *U.S. Department of Transportation Releases Policy on Automated Vehicle Development | National Highway Traffic Safety Administration (NHTSA)*. [online] Nhtsa.gov. Available at: http://www.nhtsa.gov/About+NHTSA/Press+Releases/ci.U.S.+Department+of+Transportation+Releases+Policy+on+Automated+Vehicle+Development.print [Accessed 30 May 2016].

Anon, (2016). [online] Available at: http://abcnews.go.com/blogs/lifestyle/2013/11/trucking-isnt-a-job-or-a-career-its-a-lifestyle-a-truckers-story/ [Accessed 26 May 2016].

Anon, (2016). [online] Available at: https://www.labour.gov.bc.ca/esb/igm/esr-part-1/esr-s1-long-haul-truck-driver.htm [Accessed 26 May 2016].

Archive.commercialmotor.com. (2016). *Step up to the marque | 3rd October 2013 | The Commercial Motor Archive*. [online] Available at: http://archive.commercialmotor.com/article/3rd-october-2013/30/step-up-to-the-marque [Accessed 26 May 2016].

Boagey, R. (2014). *Truck driver shortage demands changes in logistics industry - Automotive World*. [online] Automotiveworld.com. Available at: http://www.automotiveworld.com/analysis/truck-driver-shortage-demands-changes-logistics-industry/ [Accessed 30 May 2016].

Carlson, D. (2015). *Motorhome*. [image] Available at: http://www.motorhome.com/rv-reviews/class-b-trailblazer/ [Accessed 30 May 2016].

Cross, N. (2000). *Engineering design methods*. Chichester: Wiley.

Dantas, A. (2015). *Today's trucking june 2015*. [online] Issuu. Available at: https://issuu.com/joseaugustodantas/docs/today_s_trucking_-_june_2015_404fbd71639320 [Accessed 26 May 2016].

Design Taxi, (2016). [image] Available at: http://designtaxi.com/news/359811/A-Foldable-Bedroom-Office-And-Kitchen-Helps-People-Maximize-Space [Accessed 30 May 2016].

Dft.gov.uk. (2016). *Definition of vehicle categories*. [online] Available at: http://www.dft.gov.uk/vca/vehicletype/definition-of-vehicle-categories.asp [Accessed 30 May 2016].

Dieselnet.com. (2016). *Emission Standards: Europe: Heavy-Duty Truck and Bus Engines*. [online] Available at: https://www.dieselnet.com/standards/eu/hd.php [Accessed 30 May 2016].

Dufour-yachts.com. (2016). *Wood is Good! - Dufour Yachts*. [online] Available at: http://www.dufour-yachts.com/en/community/articles/106/wood-is-good [Accessed 30 May 2016].

Dye, F. (2016). *Short Haul vs. Long Haul Trucking*. [online] Work.chron.com. Available at: http://work.chron.com/short-haul-vs-long-haul-trucking-22928.html [Accessed 30 May 2016].

Ec.europa.eu. (2016). *European Commission - Competition*. [online] Available at: http://ec.europa.eu/competition/sectors/motor_vehicles/legislation/legislation_archive.html [Accessed 26 May 2016].

Ec.europa.eu. (2016). *Vehicle categories - European Commission*. [online] Available at: http://ec.europa.eu/growth/sectors/automotive/vehicle-categories/index_en.htm [Accessed 30 May 2016].

Eutruckplatooning.com. (2016). *What is Truck Platooning? - EU Truck Platoon Challenge*. [online] Available at: https://www.eutruckplatooning.com/About/default.aspx [Accessed 30 May 2016].

Fargnoli, M., Rovida, E. and Troisi, R. (2006). *The Morphological Matrix - Tool for development of Innovative Design solutions*. 1st ed. [ebook] Available at: http://axiomaticdesign.com/technology/icad/icad2006/icad2006_21.pdf [Accessed 30 May 2016].

Fogaça Truyts, C., Alves Simão de Lima, D., Motta, F., Tomassoni Coelho, L., & Franco, R. (2013). *Steps for requirements writing* (1st ed., pp. 113-114). [online] Available at: http://pmd.hostcentral.com.br/revistas/vol_10/nr_2/v10n2a05.pdf [Accessed 30 May 2016].

French, M. & French, M. (1985). *Conceptual design for engineers*. London: Design Council.

Frost & Sullivan. (2016). *Buyer Preference Shifts from Low-Cost to High-Value Commercial Trucks in China, Finds Frost & Sullivan*. [online] Available at: http://ww2.frost.com/news/press-releases/buyer-preference-shifts-low-cost-high-value-commercial-trucks-china-finds-frost-sullivan/ [Accessed 30 May 2016].

Global News. (2012). *Her mission: Persuading women to choose a job in truck industry*. [online] Available at: http://news.volvogroup.com/2012/08/29/her-mission-persuading-women-to-choose-a-job-in-truck-industry/ [Accessed 30 May 2016].

Grant, R. (2010). *Contemporary strategy analysis*. Hoboken, NJ: John Wiley & Sons.

Kendall, J. (2016). *Longer truck cabs for Europe? - SAE International*. [online] Articles.sae.org. Available at: http://articles.sae.org/13381/ [Accessed 26 May 2016].

Kirkpatrick, D. (2012). *Choosing a Compact RV or Camper for Retirement Travel - Can I Retire Yet?*. [online] Can I Retire Yet?. Available at: http://www.caniretireyet.com/choosing-a-compact-rv-or-camper-for-retirement-travel/ [Accessed 30 May 2016].

Kosow, H. and Gaßner, R. (2016). *Methods of Future and Scenario Analysis*. 1st ed. [ebook] Available at: https://www.die-gdi.de/uploads/media/Studies_39.2008.pdf [Accessed 30 May 2016].

Lau, W. (2013). *Enough with heavy truck cab interior comfort and convenience*. [online] VehicleServicePros.com. Available at: http://www.vehicleservicepros.com/article/10938042/enough-with-heavy-truck-cab-interior-comfort-and-convenience [Accessed 30 May 2016].

Level of automation. (2014). 1st ed. [ebook] Available at: http://www.sae.org/misc/pdfs/automated_driving.pdf [Accessed 30 May 2016].

McGowan, B. (2012). *The Growing Problem in Truck Cab Design - Humantech*. [online] Humantech. Available at: http://www.humantech.com/the-growing-problem-in-truck-cab-design/ [Accessed 26 May 2016].

Pahl, G. & Beitz, W. (1996). *Engineering design*. London: Springer.

Park, J. (2014). *Driver Ergonomics: Round Pegs and Oval Holes - Article - TruckingInfo.com*. [online] Truckinginfo.com. Available at: http://www.truckinginfo.com/article/print/story/2014/05/driver-ergonomics-round-pegs-and-oval-holes.aspx [Accessed 26 May 2016].

Porterfield, E. (2013). *Big city, tiny apartment: small-scale living is new trend in U.S.*. [online] Reuters. Available at: http://www.reuters.com/article/usa-apartments-micro-idUSL2N0DW00A20130602 [Accessed 30 May 2016].

Referenceforbusiness.com. (2016). *Product Life Cycle and Industry Life Cycle - strategy, organization, advantages, model, company, business, Definitions*. [online] Available at: http://www.referenceforbusiness.com/management/Or-Pr/Product-Life-Cycle-and-Industry-Life-Cycle.html [Accessed 26 May 2016].

Rns.trb.org. (2016). *TRB Research Needs Statements > Truck Driver Cabin Ergonomics*. [online] Available at: https://rns.trb.org/dproject.asp?n=36171 [Accessed 26 May 2016].

Schmidt, C. (2016). *Wanted in Europe: More Truck Drivers*. [online] WSJ. Available at: http://www.wsj.com/articles/SB10000872396390443524904577651624294475232 [Accessed 30 May 2016].

Sivaraman, V. (2016). *Basic ergonomics in automotive design*. [online] Slideshare.net. Available at: http://www.slideshare.net/sudhavel/basic-ergonomics-in-automotive-design [Accessed 26 May 2016].

Stalk, G. (1988). *Time—The Next Source of Competitive Advantage*. [online] Harvard Business Review. Available at: https://hbr.org/1988/07/time-the-next-source-of-competitive-advantage [Accessed 30 May 2016].

Summers, J. (2016). *Design Tool - Function Means Tree*. 1st ed. [ebook] Clemenson University. Available at: http://www.clemson.edu/ces/cedar/images/c/c0/08-FunctionMeansTree.pdf [Accessed 30 May 2016].

Thinking inside the box. (2014). *Commercial Motor, 221*(5592), 42-45.

Ulrich, K. & Eppinger, S. (2012). *Product design and development*. New York: McGraw-Hill/Irwin.

Volvogroup.com. (2016). *Volvo's founders - Our founders & presidents : Volvo Group Global*. [online] Available at: http://www.volvogroup.com/GROUP/GLOBAL/EN-GB/VOLVO%20GROUP/HISTORY/VOLVOSFOUNDERS/PAGES/VOLVO_FOUNDERS.ASPX [Accessed 30 May 2016].

Volvotrucks.com. (2016). *About Volvo Trucks - About Us : Volvo Trucks*. [online] Available at: http://www.volvotrucks.com/trucks/global/en-gb/aboutus/Pages/about_volvo_trucks.aspx [Accessed 30 May 2016].

Volvotrucks.com. (2016). *Cab - Specifications : Volvo Trucks - United Kingdom & Ireland*. [online] Available at: http://www.volvotrucks.com/trucks/uk-market/en-gb/trucks/volvo-fh-series/specifications/Pages/cab-specifications.aspx [Accessed 30 May 2016].

Volvotrucks.com. (2016). *Driveline - Driveline : Volvo Trucks - United Kingdom & Ireland*. [online] Available at: http://www.volvotrucks.com/trucks/uk-market/en-gb/trucks/volvo-fh-series/driveline/Pages/driveline.aspx [Accessed 30 May 2016].

Volvotrucks.com. (2016). *FH12 and FH16 - 1990s : Volvo Trucks*. [online] Available at: http://www.volvotrucks.com/trucks/global/en-gb/aboutus/history/1990s/pages/fh12_and_fh16.aspx [Accessed 30 May 2016].

Volvotrucks.com. (2016). *introduction - 1920s : Volvo Trucks*. [online] Available at: http://www.volvotrucks.com/trucks/global/en-gb/aboutus/history/1920s/Pages/introduction.aspx [Accessed 30 May 2016].

Weiss, R. (2013). *Germany Wants More Truck Drivers*. [online] Bloomberg.com. Available at: http://www.bloomberg.com/news/articles/2013-08-29/germany-wants-more-truck-drivers [Accessed 30 May 2016].

Wifi onboard. (2016). *Wifionboard - Internet Access Via Wifi hotspots on yachts, motorhomes, caravans and more*. [online] Available at: http://www.wifionboard.co.uk/ [Accessed 30 May 2016].

Wordpress, (2016). *Fisher 30 For Sale*. [image] Available at: https://fisher30forsale.files.wordpress.com/2010/08/p1030268.jpg [Accessed 30 May 2016].

8.1 Figure References

Figure 1: Volvotrucks.com. (2016). *FH12 and FH16 - 1990s : Volvo Trucks*. [online] Available at: http://www.volvotrucks.com/trucks/global/en-gb/aboutus/history/1990s/pages/fh12_and_fh16.aspx [Accessed 30 May 2016].

Figure 2, Figure 3 and Figure 4: Volvo Group Trucks Technology,. (2016). *Cab specifications for the new Volvo FH*. [online] available at: http://www.volvotrucks.com/trucks/uk-market/en-gb/trucks/volvo-fh-series/specifications/Pages/cab-specifications.aspx [Accessed 30 May 2016].

Figure 5: Grant, R. (2010). Contemporary strategy analysis. Hoboken, NJ: John Wiley & Sons.

Figure 6, Figure 7: Cross, N. (2000). *Engineering design methods*. Chichester: Wiley.

Figure 9: Allsteel, S. & Allsteel, E. (2006). *Ergonomics and Design A Reference Guide* (1st ed., p. 6). [pdf] Available at: http://www.allsteeloffice.com/synergydocuments/ergonomicsanddesignreferenceguidewhitepaper.pdf [Accessed 30 May 2016].

Figure 10 and Figure 11: Sougata Karmarkar,. (2016). *Binocular field view in planes*. [image] Available at: http://www.dsource.in/course/basic-ergonomics-automotive-design/module-2/visual-field-and-visual-obstruction [Accessed 16 June 2016]

Figure 12, Figure 13, Figure 16, Figure 17 and Figure 23: Ulrich, K. & Eppinger, S. (2012). *Product design and development*. New York: McGraw-Hill/Irwin.

Figure 15: Kosow, H. and Gaßner, R. (2016). *Methods of Future and Scenario Analysis*. 1st ed. [ebook] Available at: https://www.die-gdi.de/uploads/media/Studies_39.2008.pdf [Accessed 30 May 2016].

Figure 18: Summers, J. (2016). *Design Tool - Function Means Tree*. 1st ed. [ebook] Clemenson University. Available at: http://www.clemson.edu/ces/cedar/images/c/c0/08-FunctionMeansTree.pdf [Accessed 30 May 2016].

Figure 19: Fogaça Truyts, C., Alves Simão de Lima, D., Motta, F., Tomassoni Coelho, L., & Franco, R. (2013). *Steps for requirements writing* (1st ed., pp. 113-114). [online] Available at: http://pmd.hostcentral.com.br/revistas/vol_10/nr_2/v10n2a05.pdf [Accessed 30 May 2016].

Figure 22: Fargnoli, M., Rovida, E. and Troisi, R. (2006). *The Morphological Matrix - Tool for development of Innovative Design solutions*. 1st ed. [ebook] Available at: http://axiomaticdesign.com/technology/icad/icad2006/icad2006_21.pdf [Accessed 30 May 2016].

Figure 23 and Figure 25: Carlson, D. (2015). *Motorhome*. [image] Available at: http://www.motorhome.com/rv-reviews/class-b-trailblazer/ [Accessed 30 May 2016].

Figure 26: Design Taxi, (2016). [image] Available at: http://designtaxi.com/news/359811/A-Foldable-Bedroom-Office-And-Kitchen-Helps-People-Maximize-Space [Accessed 30 May 2016].

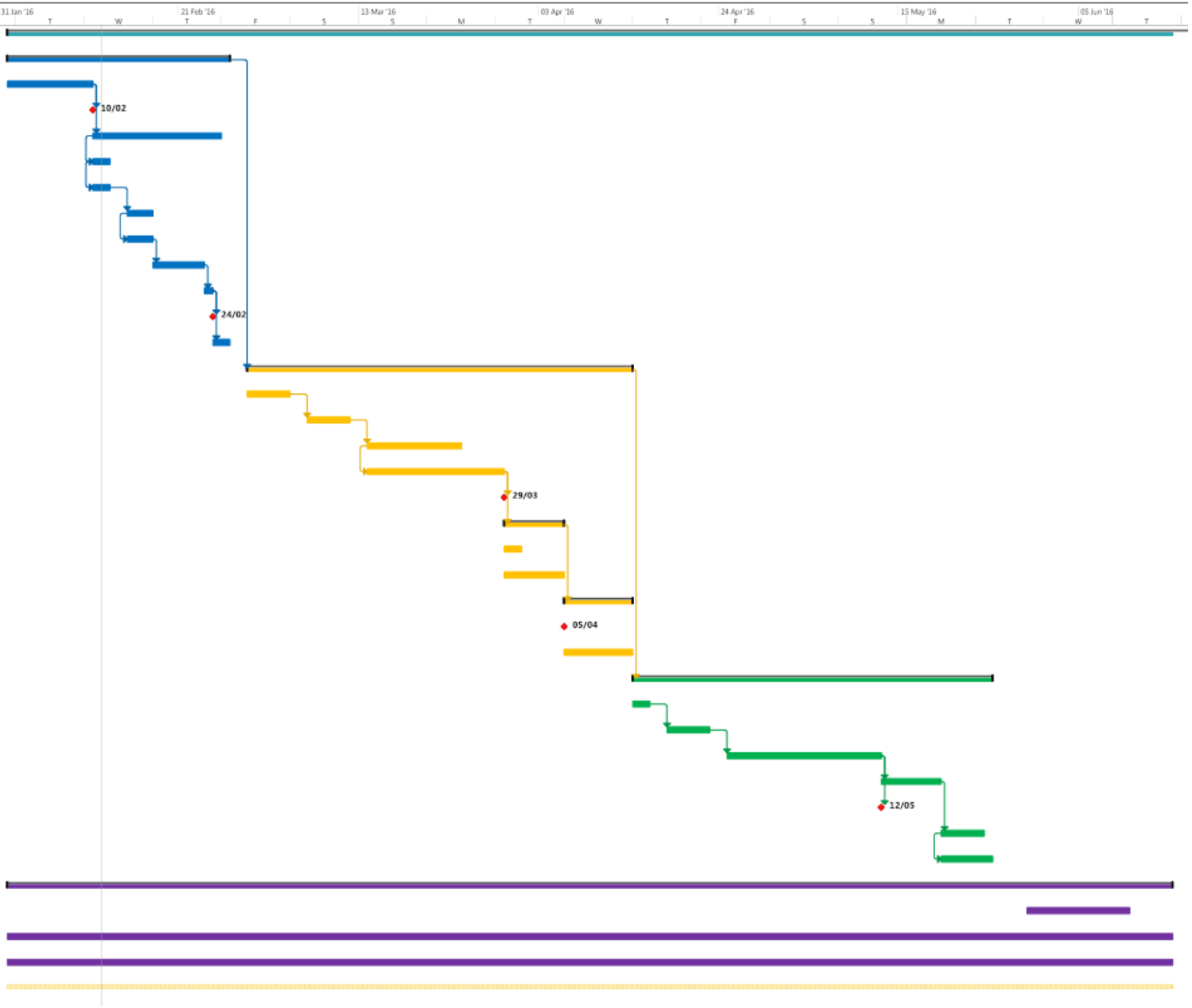
Figure 27: Wordpress, (2016). *Fisher 30 For Sale*. [image] Available at: https://fisher30forsale.files.wordpress.com/2010/08/p1030268.jpg [Accessed 30 May 2016].

Figure 29: Level of automation. (2014). 1st ed. [ebook] Available at: http://www.sae.org/misc/pdfs/automated_driving.pdf [Accessed 30 May 2016].

9. APPENDICES

Appendix A: Time plan

Task Name	Duration	Start	Finish
Designing the interior cab of future trucks	**20 wks**	**Mon 01/02/16**	**Fri 17/06/16**
Concept Study & Project Planning	**20 days**	**Mon 01/02/16**	**Fri 26/02/16**
General Definitions	8 days	Mon 01/02/16	Wed 10/02/16
Constraints, Project Planning	0 days	Wed 10/02/16	Wed 10/02/16
Research	11 days	Thu 11/02/16	Thu 25/02/16
Literature review	2 days	Thu 11/02/16	Fri 12/02/16
Trend analysis	2 days	Thu 11/02/16	Fri 12/02/16
Market analysis	3 days	Mon 15/02/16	Wed 17/02/16
Interviews and visits	3 days	Mon 15/02/16	Wed 17/02/16
Customer needs	4 days	Thu 18/02/16	Tue 23/02/16
Scope Review	1 day	Wed 24/02/16	Wed 24/02/16
Scope narrowed	0 days	Wed 24/02/16	Wed 24/02/16
Requirements and specification	2 days	Thu 25/02/16	Fri 26/02/16
Concept Development	**33 days**	**Mon 29/02/16**	**Wed 13/04/16**
Function definition	5 days	Mon 29/02/16	Fri 04/03/16
Brain Storm	5 days	Mon 07/03/16	Fri 11/03/16
Mockup for CG	9 days	Mon 14/03/16	Thu 24/03/16
Generation of concepts	12 days	Mon 14/03/16	Tue 29/03/16
Concept Discussion	0 days	Tue 29/03/16	Tue 29/03/16
Concept Evaluation	**5 days**	**Wed 30/03/16**	**Tue 05/04/16**
Regarding the requirements	2 days	Wed 30/03/16	Thu 31/03/16
Trade-off analysis	5 days	Wed 30/03/16	Tue 05/04/16
Decision of the concept	**6 days**	**Tue 05/04/16**	**Wed 13/04/16**
Final concept decision	0 days	Tue 05/04/16	Tue 05/04/16
Finalizing the concept	6 days	Wed 06/04/16	Wed 13/04/16
System Level Design	**30 days**	**Thu 14/04/16**	**Wed 25/05/16**
Learning time	2 days	Thu 14/04/16	Fri 15/04/16
Review and concept improvement	5 days	Mon 18/04/16	Fri 22/04/16
CAD/CAID modeling	14 days	Mon 25/04/16	Thu 12/05/16
System Level integration	5 days	Fri 13/05/16	Thu 19/05/16
Work evaluation	0 days	Thu 12/05/16	Thu 12/05/16
Design finalization	3 days	Fri 20/05/16	Tue 24/05/16
Visualization and rendering	4 days	Fri 20/05/16	Wed 25/05/16
Documentation and Adm	**98 days**	**Mon 01/02/16**	**Wed 15/06/16**
Presentation	10 days	Mon 30/05/16	Fri 10/06/16
Chalmers Report	98 days	Mon 01/02/16	Wed 15/06/16
Volvo Report	98 days	Mon 01/02/16	Wed 15/06/16
Weekly meetings	98 days	Mon 01/02/16	Wed 15/06/16



Appendix B: Product Constraints and List of requirements

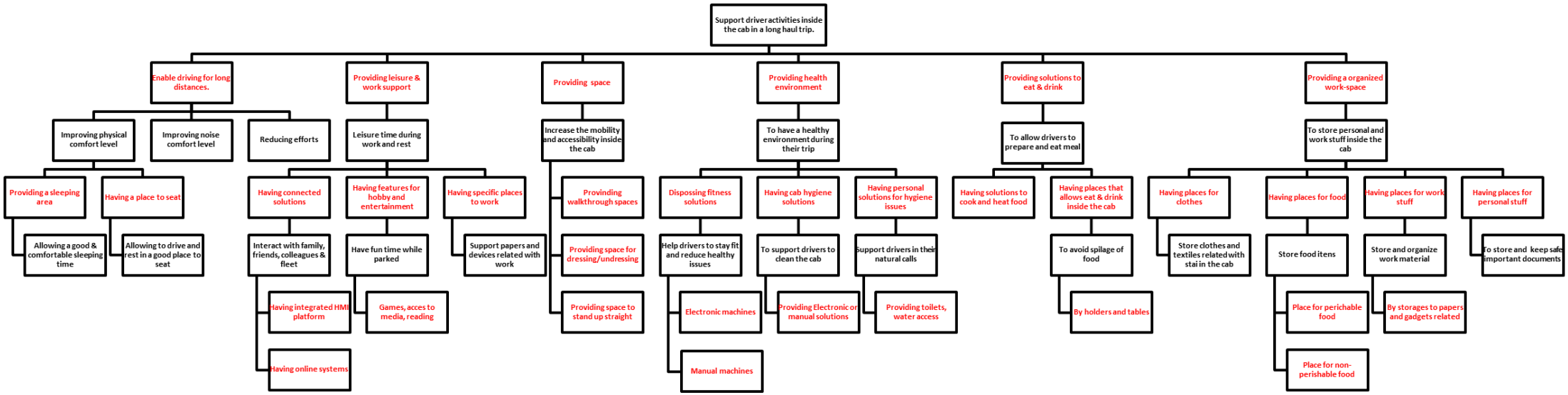
Ergonomic and Design Criteria		Verification Method	Value	Justification	Applied in the concepts (Yes/No)
Sleep area					
R	Sleeping dimensions	CAD, virtual analysis	2000 x 900 mm	To increase the sleeping comfort.	Yes
R	No protruding object with radii smaller than	CAD, virtual analysis	Min radii 7 mm 0-230 mmm above bed. - can be changed	To avoid injuries.	No
R	Sleeping height with adjustable top bunk in lowermost position	CAD, virtual analysis	Min 550 mm	To avoid claustrophobic feeling.	Yes
R	Mattress width at Y0	CAD, virtual analysis	Min 700mm	To have increased sleep comfort.	Yes
D	Fully foldable top bunk in applicable variants. It could be fully foldable against the wall and should have a reachable fixation in that position.	CAD, Virtual analysis, Crash test	Generic - Newton	To withstand the crash test.	Yes
Storages					
R	Rear wall storage	CAD, virtual analysis	Depth min 190 mm Opening min 65,5 mm in x. Top of storage shall be min 170 mm under top bunk.	To allow easily accessible storages.	Yes
R	Rear wall panel storage, weight of stored items	CAD, virtual analysis	Density 0,3 (10 l storage= 3kg)	To have quality and safety.	No
R	Rear wall panel storage, forces that can be applied by user in bunk	CAD, virtual analysis	300 N	To avoid overloads and breaking parts	No
R	To have handle in under bunk storage with finger grips.	CAD, virtual analysis	Min 80 mm wide. Max 50 mm in from front edge of bunk.	To avoid risk of pinching while operating.	No
R	It should be possible to slide out the refrigerator without any kind of hurdle.	CAD modeling and Visual verification	Generic	To have fresh drinks and reach snacks.	Yes
D	To have good storage capacity	CAD modeling and Visual verification	>1000 liters	Since most of the drivers travel long distances. They tend to take a lot of things with them.	Yes
Walkthrough					
D	Walk through and moving around in the cab should be there.	CAD, virtual analysis	Generic - Meters	Providing space to perform common activities.	Yes
R	Nothing should protrude above seat cushion level and hinder the movement.	CAD, virtual analysis	Generic	To have good comfort when moving from driver seat in to living area.	Yes
R	Nothing should stick up above or forward of seat cushion level and hinder the movement.	CAD, virtual analysis	Generic	To have good comfort when moving from driver seat in to Living area.	Yes
Usage & Visibility					
R	The contrast between dark and light areas shall be soft (no sharp edges)	CAD modeling and Visual verification	Generic - Candela	To improve visibility and save energy in lights.	No
R	Visibility - target angles a-pillar	CAD, virtual analysis	Generic -Meters	To enhance safety driving.	No
R	Visibility - upward visibility	CAD, virtual analysis	Generic -Meters	To enhance safety driving.	No
R	CCP and climate control panel should be visible from bunk	CAD, virtual analysis	Generic - Meters	To allow setups in loco.	No

R	The backrest of seats should be quickly foldable and should be moved away from the living area	CAD, virtual analysis	Angle for adjustments	To improve a comfortable driving.	Yes
R	The control(s) shall be reachable and visible from the living area for all targeted users (F05 to M99) and should have enough clearance around them for easy operation.	CAD, virtual analysis	Generic - Meters	To improve ergonomic usage.	No
R	The size and shape of the control(s) should allow for comfortable operation of the functions.	CAD, virtual analysis	Generic	To improve ergonomic usage.	No
R	The force needed to operate the control(s) should be higher than the Friday vehicle	CAD, virtual analysis	Generic -Newton	Avoid efforts.	No
R	If the folding mechanism is electrical, the speed should be significantly improved as compared to the Friday vehicle. The electrical folding mechanism needs to work when truck is in off Mode (or Living Mode?).	CAD, virtual analysis	Generic	To reduce the time wasted in adjustments.	No
	General				
R	Different anthropometric data should be considered	CAD, virtual analysis and prototyping	Generic -Meters	To achieve one range of the population.	Yes
R	To keep the current dashboard design	CAD verification, prototyping	Generic	Scope of the project is limited	Yes
R	Cab dimension	CAD modeling, geometric dimensioning and prototyping	Current + 300 mm in the length	It is as per the European legislations and norms.	Yes
R	To have features like Radio, tachograph in the front shelf - above the drivers head	CAD verification, prototyping	Generic	Due to harness routes.	Yes
R	If considered, microwave must be placed in the front shelf	CAD verification, prototyping	Generic	When crash tested, it was noted that the safest place to have a microwave is on the front shelf.	Yes
R	To have side storages with exterior access	CAD verification, prototyping	Generic	The drivers want to have access from outside and also want to keep some of their work clothes or tools.	Yes
Legal criteria		**Verification Method**	**Value**	**Justification**	
R	The driver should wear seatbelt while driving	Legal complaint	Checking, Sensors	This provides safety to the drivers under all driving conditions.	Yes
R	The drivers should have a break after 4 hrs. of driving	Legal complaint	Time	This is as per the European legislation for the drivers to take rest after some continuous hours of journey.	Yes
Features performance criteria		**Verification Method**	**Value**	**Justification**	
R	Sleeping area for the drivers	Driver clinics and prototyping	Meters	This is helpful for the drivers to stay active during driving and to have some rest.	Yes
D	Sleeping area for the passengers	Driver clinics and prototyping	Meters	For the passengers to have some rest and also drivers can use this as a relaxing chair when parked.	Yes

R	Features in driver seat	Driver clinics and prototyping	Meters, load and angles	To have ergonomic and comfortable position in seats for drivers while driving.	Yes
R	Feature to passenger seat	Driver clinics and prototyping	Meters, load and angles	To have ergonomic and comfortable position in seats for passengers as well as for the drivers when they are using it while parked.	Yes
R	Holders for food and drinks	Crash test virtual analysis	Newton	To avoid the spillage of drinks and food when vehicle is either parked or moving	Yes
R	Features to prepare food	Crash test virtual analysis	Power, Capacity	To reheat, cook or bake all kinds of food products.	Yes
R	Features for storing perishable food	Crash test virtual analysis	Power and volume	It helps to preserve perishable by maintaining the appropriate temperature.	Yes
R	Cab hygiene features	Driver clinics and prototyping	Capacity, power	The cab might become unclean sometimes and some people like to keep cab very clean.	Yes
D	Personal hygiene features	Driver clinics and prototyping	Volume, Power,	Some people are very self-cautious about their personal hygiene and lot of women do prefer it.	No
D	Internet connectivity	Signal testing	Mb/s	To stay connected with family and fleet and to have media entertainment.	Yes
R	Infotainment feature	Driver clinics and prototyping	Generic	To have a unique interface which increase the product value as well as adds value to customer.	No
R	Leisure activities	Driver clinics and prototyping	Generic	To have relaxation and fun time when parked like board games etc.	Yes
R	Store personal stuff	CAD modeling, virtual analysis and Crash test	Liters	To store cloths, books, magazines and personal stuff.	Yes
R	Store work stuff	CAD modeling, virtual analysis and Crash test	Liters	Some of the legal papers are to organize which could be very useful when needed.	Yes
D	Store electronic gadgets	CAD modeling, virtual analysis and Crash test	Liters	To avoid damage to the electronic gadgets and prevent theft.	Yes
D	Store valuable stuff	CAD modeling, virtual analysis and Crash test	Liters	To prevent the theft of documents and money.	Yes

	Customer needs
R = Requirements	**Comfort**
D = Desire	**Eat & Drink**
	Hygiene
	Fun & Socialize
	Store and Organize

Appendix C: Function means tree



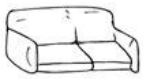
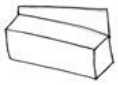
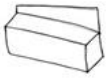
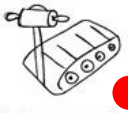
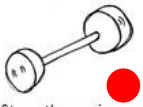
Appendix D: Benchmarking – Current trucks

Categories / Truck Model	Cab & Personal Cleanning	Driving Comfort	Eletronics	Kitchen Equipament	Office Equipament & Tables	Seats	Sleeping area	Storage & Save
VOLVO FH Series	Eletric drying Towel hanger Waste bin Ashtray Vanity Mirror	Gear lever at seat Sunblind Sun visor Mats	Installation for TV Hands-free phone system Dashb LCD interface Integrated sound system	Coffe machine Microwave Refrigerator Cup/Bottle holder Kettle	Bunk table Writing pad Devices mounts	Pneumatic adjustment Armrest Rotatable pas. seat Climating system Seat overs	Reclining bunk Reading lamp Bunk curtains 2 beds available Digital setup display	Safety box Lower bunk storages Upper bunk storages Upper windsh storage Side wall compartments Rear wall compartments
SCANIA R Series	Compressed Air Gun Waste bin Ashtray	Gear lever at dashb Sunblind Sun visor Mats	Installation for TV Hands-free phone system Dashb LCD interface Integrated sound system	Coffe machine Microwave Refrigerator Kettle Electric lunchbox heater Cup/Bottle holder	Passenger seat table Bunk table Writing pad Devices mounts Centre table	Pneumatic system Armrest Mic system Climating system Seat covers	Extendable bed Reading lamp Bunk curtains 2 beds available Digital Setup display	Safety box Lower bunk storages Upper bunk storages Upper windsh storage Side wall compartments Rear wall compartments
Mercedes-Benz Actros Series	Bag models (food, clothes) Waste bin Vacuum cleaner Ashtray	Gear lever at dashb Sunblind Center footrest Sun visor Mats	LCD detachable pad Hands-free phone system Dashb LCD interface Integrated sound system Smart Eletronic Key	Coffe Machine Microwave Refrigerator Kettle Cup/Bottle holder	Passenger seat Table Computer mounts Swivel table	Pneumatic system Armrest Climating system Seat cover	Reclined bunk Reading lamp Bunk curtains 2 beds available Analogic Setup display	Lower bunk storages Upper bunk storages Upper windsh storage Side wall compartments
RENAULT TRUCKS Range T	Compressed Air Gun Waste bin Ashtray Vacuum cleaner	Gear Lever at dashb Sunblind Sun visor	Installation for TV Hands-free system Dashb LCD interface Integrated sound system Portable DVD	Coffe Machine Microwave Refrigerator Cup/Bottle holder Kettle	Center Table Writing pad Devices mounts	Pneumatic system Armrest Climated system	Reading lamp Bunk curtains 2 beds available Digital Setup display Backrest	Lower bunk storages Upper bunk storages Upper windsh storage Side wall compartments
DAF XF Series	Waste bin Vacuun cleaner	Gear Lever at dashb Sunblind Sun visor	Hands-free system Dashb LCD interface Integrated sound system	Cup/ Bottle Holder Refrigerator	Center Table	Pneumatic system Armrest Climated system	Reading lamp Bunk curtains 2 beds available Analogic Setup display	Lower bunk storages Upper bunk storages Upper windsh storage Side wall compartments Rear wall compartments
MAN TGX Series	Waste bin Ashtray	Gear Lever at dahsb Sunblind Sun visor	Hands-free system Dashb LCD interface Integrated sound system	Cup/ Bottle Holder Refrigerator	Center Table	Pneumatic system Armrest Climated system	Reading lamp Bunk curtains 2 beds available	Lower bunk storages Upper bunk storages Upper windsh storage Rear wall compartments
IVECO Stralis Hi-Way	Waste bin Ashtray	Gear Lever at dahsb Sunblind Sun visor	Hands-free system Dashb LCD interface Integrated sound system	Microwave Refrigerator Cup/Bottle holder		Pneumatic system Armrest Climated system	Reading lamp Bunk curtains 2 beds available Reclining bunk	Lower bunk storages Upper bunk storages Upper windsh storage Side compartments
Source	Long Haul trucks competitors - Solutions developed by the companies, considering high-end version. Available by order and available on official accessories catalog							

Appendix E: Benchmarking – Future trucks

Concept	Released	Technological approach	Ergonomic aspects	Design aspects	Focus
 **Freightliner Revolution Truck**	**2012**	Aluminium frame Radiator package - changed place Cameras instead of rear view mirrors Analogic with LCD screen cluster Logs in tablets	Back door Side storages Work station - Tables Available Storages below passenger seat	Aerodynamic Shapes to achieve lower fuel consumption	Focused on a conceptual truck cab, in aerodynamic and ergonomic aspects
 **Walmart Advanced Vehicle Experience**	**2013**	Micro turbine, battery store and electric motor Electronic dashboard (Tablets interface) carbon fibre trailer	Sliding doors Single seat in the centre Single Foldable lower bunk Upper bunk storages Interior Mirrors Clothes hanger Driver seat can rotate 180 degrees	Aerodynamic shapes enhanced due to powertrain set	Focused on fuel reduction by new powertrain and body design
 **Mercedes-Benz Future truck 2025**	**2014**	Highway pilot: max 85km/h Steers, brake and accelerate autonomously V2V and V2I - Shared information Integrated HMI system - Gadget integration Unique platform for work and leisure Cameras instead of rear view mirrors	Single Upper fixed bunk swivel driver seat (45 dg) "Sofa" passenger seat Clean Design No kitchen features presented No storages presented Easy to move inside the cab	Front similar to new Actros. Incorporated lamps (led system)	Extremely focused on vehicle autonomous technologies.
 **Freightliner Inspiration Truck**	**2015**	Highway pilot: 0 to max vehicle speed Steers, brake and accelerate autonomously Radar and camera to track the jam (V2V) Integrated HMI system - Gadget integration Cameras instead of rear view mirrors	Single Foldable Lower bunk Clean design No kitchen features presented No storages presented	Quite similar to current US trucks	Focused on autonomous technology which comply with regulations.

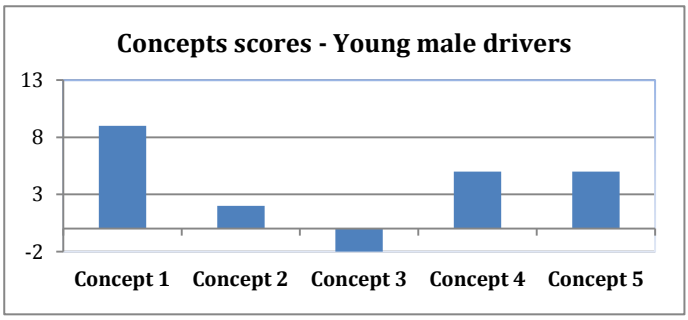
Appendix F: Morphological matrix

Functions	Morphological Matrix				
Main	"Support driver activities inside the cab, in a long haul trip."				
2nd Level					
Comfortable Sleep	 Bed	 Hammock	 Sleeping Bag	 Sofa	 Mat
Comfortable drive position	 Bench	 Massage chairs	 Electrically Actuated Seat	 Pneumatic Actuated Seat	 Hydraulic Actuated Seat
Comfortable rest position	 Sofa	 Bean Bag	 Chairs	 Bench	
Interaction with Family and colleagues	 Mobile communication	 Computers	 Ham radios		
Fun Activities When Parked	 Electrical Applications	 Reading	 Games	 Online Applications	
Fitness Support Inside Cab	 Endurance exercises	 Strength exercises	 Stretching exercises		
Cleaning Support inside the Cab	 Electrical surfaces cleaner	 Manual surfaces cleaner	 Waste bins	 Pneumatic systems	
Personal Cleaning Support	 Bathroom Sink	 Toilet	 To take shower	 Laundry	
Support to avoid Food Spillage	 Tables	 Holders			
Cloth Storing Supports	 Box	 Hanger	 Drawer	 Cabinet	 Suit Case
Food Storing supports	 Fridge	Thermal Box	Coolers	Cabinet	Drawer
Work Store Supports	Safety Locker	Drawer	Glove Compartment	Cabinet	
Food Prepare Supports	Microwave	Oven	Coffee Machine	Stove	Kettle

Excluded solutions

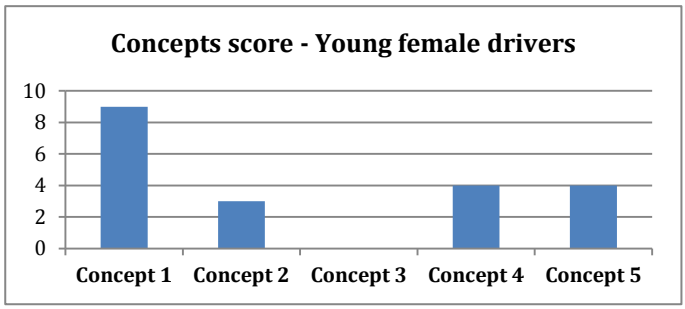
Appendix G: Pugh matrix results – Personas point of view

- **Rank of concepts and comments of the young male drivers.**



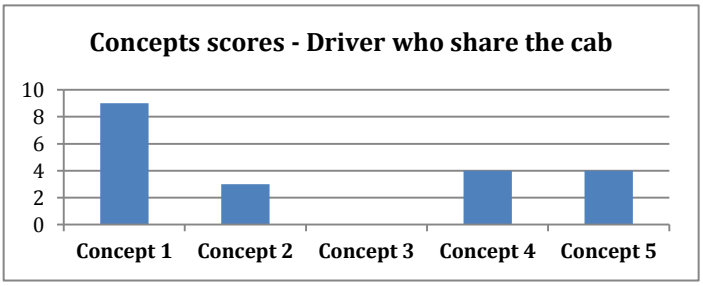
Comments	
Concept 1	No comments
Concept 2	They prefer bunk always fixed. If no, the bunk should be easy to assemble
Concept 3	The frame is a barrer to walk and to move They could feel congested in the bunk area due to the frame
Concept 4	They prefer bunk always fixed. If no, the bunk should be easy to assemble
Concept 5	They would prefer single bunk accept have double bed solution

- **Rank of concepts and comments of the young female drivers.**



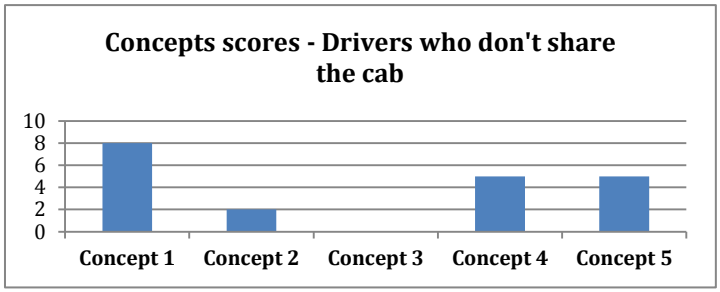
Comments	
Concept 1	No comments
Concept 2	They prefer bunk always fixed. If no, the bunk should be easy to assemble
Concept 3	The frame is a barrer to walk and to move They could feel congested in the bunk area
Concept 4	They prefer bunk always fixed. If no, the bunk should be easy to assemble
Concept 5	No comments

- **Rank of concepts and comments of the driver who share the cab.**



Comments	
Concept 1	No comments
Concept 2	They prefer bunk always fixed. If no, the bunk should be easy to assemble
Concept 3	The frame is a barrer to walk and to move They could feel congested in the bunk area
Concept 4	They prefer bunk always fixed. If no, the bunk should be easy to assemble
Concept 5	No comments

- **Rank of concepts and comments of the driver who don't share the cab.**



Comments	
Concept 1	Could have problems to access the bunk due to the age
Concept 2	They prefer bunk always fixed. If no, the bunk should be easy to assemble
Concept 3	The frame is a barrier to walk and to move They could feel congested in the bunk area
Concept 4	They prefer bunk always fixed. If no, the bunk should be easy to assemble
Concept 5	They prefer bunk always fixed. They prefer have single bed.