Sensitivity of H-point Parameters in CAE Prediction for Automotive Seats

Master's thesis in Product Development

THI HELLQVIST
TOBIAS RATTFELT

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

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Supervisor: Chella Ganesan Thangam, Seats Department, Volvo Car Corporation
Examiner: Lars Lindkvist, Div. Product Development, Product and Production Development

Department of Product and Production Development
Division of Product Development
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Positioning of H-point Machine in the PRIMER software

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Abstract

In the automotive industry, the position of the occupant is determined early in the development process through a reference point termed Seating Reference Point (SgRP). Since the SgRP influences many dimensions in the car, it is of greatest importance that the Hip-point (H-point), the cross section of the torso line and the thigh line of the human body, corresponds to this SgRP during the development of seats. Volvo Car Corporation (VCC) is developing a virtual method, to predict the H-point earlier, to shorten the lead times in the product development process.

The purpose of this thesis is to explore what parameters affect the H-point of the Hip-point Machine (HPM) in Computer Aided Engineering (CAE), and to answer the question of whether it is the same parameters affecting the H-point for all seat types, or if it is individual. To identify the parameters that significantly impacted the H-point, a Sensitivity Analysis was performed, where the Finite Element Method (FEM) software LS-DYNA was used to run the simulations of the seat, and preparations of the CAE models took place in ANSA and PRIMER software. The simulations were designed by Design of Experiments (DOE).

The result showed that several parameters had an impact on the H-point, but that three parameters were in common for the two seat types investigated, in vertical direction (Z). The results showed, despite the found similarities between the seats, that it was not possible to apply the results of one seat type to another one. The accuracy of the used finite element models need improvement to increase the overall accuracy of the Sensitivity Analysis.

Keywords: Seating Reference Point, Hip-point, Volvo Car Corporation, Parameters, Computer Aided Engineering, Sensitivity Analysis, Design of Experiments, LS-DYNA, ANSA, PRIMER.

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Thi Hellqvist and Tobias Rattfelt, Gothenburg, June 2017

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Acronyms

In this section, acronyms and abbreviations that are used in the report, are presented.

2D	Two Dimensional
3D	Three Dimensional
CAD	Computer Aided Design
CAE	Computer Aided Engineering
DOE	Design of Experiment
ECE	Economic Commission for Europe
FEA	Finite Element Analysis
FEM	Finite Element Method
FMVSS	Federal Motor Vehicle Safety Standards
HPM	Hip-Point Machine
H-point	Hip-Point
NHTSA	National Highway Traffic Safety Administration
OWS	Occupant Weight Sensor
SAE	Society of Automotive Engineers
SBR	Seat Belt Reminder
SgRP	Seating Reference Point
SPA	Scalable Platform Architecture
SUV	Sport Utility Vehicle
UNECE	United Nations Economic Commission for Europe
U.S	United States
USA	United States of America
VCC	Volvo Car Corporation

1

Introduction

This master thesis report describes the investigation of seat design parameters and their influences on the H-point coordinates, which is performed in the CAE environment of Volvo Car Corporation.

1.1 Background

In the automotive industry, there are many factors playing a role for the customer when purchasing a new premium car, e.g. safety and comfort. The competition in the automotive industry keeps getting tougher, with shorter lead times, and the expectations from the customers are getting higher with new technology. Volvo Car Corporation (VCC) is one of the car manufacturers, with a focus of premium cars, that needs to stand out within this industry. VCC has global markets including China, Europe and United States of America (USA), and the company had in 2016 a sales volume of 534 332 cars. (Volvo Cars, 2017)

The new Volvo XC90, a premium Sport Utility Vehicle (SUV), has contributed to this success with its Scalable Platform Architecture (SPA). The SPA platform provides the car with higher safety protection and a modern flexibility within the interior and seats. (Volvo Cars, 2014)

The customer's relation to comfort, is often connected to the seat within the car. The overall comfort can be described through a combination of factors, e.g. thermal comfort, static comfort, and dynamic comfort. While dynamic comfort is more related to the occupant's experience of vibrations, the static comfort is related to the seat itself, and what form and support it provides the occupant with. This affects the posture and orientation of the occupant. (Ippili, Davies, Bajaj, & Hagenmeyer, 2008)

To enable different parts of the car to be designed simultaneously and perform seat comfort analyses, an important reference point termed Seating Reference Point (SgRP) is determined early in the development process. The purpose of this is to define and describe the positioning of the occupant and the dimensions of the vehicle. Since this reference point is used as a base for many positions and dimensions in the car, it is of greatest importance that the Hip-point (H-point) corresponds to the SgRP, during the development of seats. The H-point is positioned between the torso line and the thigh line of the human body, see Figure 1.1.

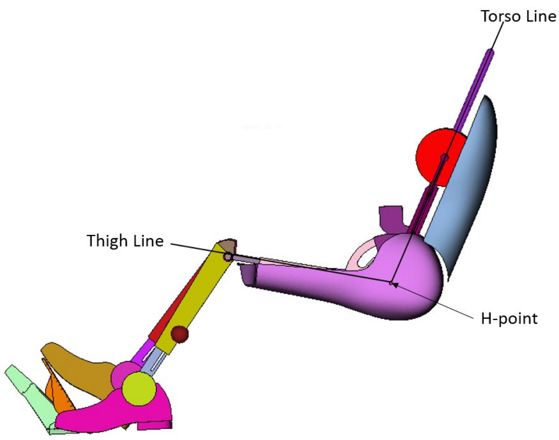

Figure 1.1: Position of the H-point.

The H-point's correlation to the SgRP is being confirmed through physical measurements, where a manikin is positioned in a physical prototype seat, see Figure 1.2, and the coordinates of the H-point is measured and compared to the coordinates of the SgRP. If the distance between the physical H-point and the theoretical SgRP exceeds the accepted tolerance, then a redesign of the seat has to be made, which in turn could cause time consuming and costly loops in the product development process. (Gkikas, 2012)

Figure 1.2: Manikin positioned in a physical seat. Photo: Volvo Cars.

To avoid these kinds of loops and strive for shorter lead times, virtual methods of Computer-Aided Engineering (CAE) methods are gradually more used within the industry. This enables predictions in the early design phases, even though no physical product or prototype exists. VCC is developing such a method with the intention of predicting the H-point through CAE, but before implementing it to the product development process, further knowledge is needed about how the parameters are affecting the H-point in CAE and with what sensitivity.

1.2 Purpose

The purpose of this master thesis is to investigate the relations between seat design parameters and the coordinates of the H-point. The deliverables are guidelines regarding what parameters affect the H-point coordinates and if the same parameters affecting the H-point of one specific seat can be applied on another seat type. The intention with the deliverables is to facilitate the development of seats, with respect to the position of the H-point.

An additional, secondary purpose, is to investigate the materials of foam, used in CAE, and to suggest a suitable material combination of foam types to represent the reality and handle variations of the H-point.

1.3 Objectives

To provide a clear understanding of the design parameters' influence on the H-point, a Sensitivity Analysis of the design parameters and material properties is performed, by simulating different seats with varying parameters in a CAE environment.

To suggest the most suitable material combination to use in the CAE models with respect to the variations of H-points, an analysis is performed where different material combinations of the same seat gets simulated.

1.3.1 Research Questions

To achieve the purpose, five research questions are stated, that are answered during the project. Each research question is followed by a description that explains what it means and why it is important.

1. *Are the same parameters affecting the H-point of all seat types, or is it individual?*
   Since it is unknown whether different seat types have the same parameters affecting the H-point, or if it is individual for the type of the seat, it is of interest to answer this question.

2. *What parameters influence the coordinates of the H-point?*
   To clarify what parameters are more influential than others is important, since parameters within the seat can affect the position of the occupant and its H-point differently.

3. *How does these parameters interact and influence the H-point?*
   To understand the relations, it is important to identify what interactions between the parameters that affect the H-point and how the parameters individually are influencing the H-point, and in what directions.

4. *What guidelines for parameters can be established and with what accuracy?*
Based on how the parameters influence the coordinates of the H-point, it may be possible to establish guidelines for what parameters to consider, in order to move the H-point in a desired direction. The guidelines may be general for all seat types or applied for specific cases. It is also important to know how accurate the guidelines are, to know if one should rely on them or if further investigations are needed.

5. *What materials are suitable to use together, to represent the hardness of the foam in the CAE method? Why?*
In the CAE method, it is possible to choose different material types with the same hardness. What material types to combine, to handle the variations of H-point and represent the reality, are therefore important to suggest.

1.4 Limitations

- The investigated design parameters does not consider the structure of the seat, such as the spring mat and the rails, to limit the amount of parameters.

- The H-point coordinates in Z-direction are prioritized, since the Z-direction is the most critical one. The X-direction and Torso angle are also considered, but the Y-direction is not analyzed to the same extent, since the occupant is positioned in the middle of the seat.

- The simulations takes at least 30 hours to run. This limits the thesis when considering numbers of simulations and combinations of seats to explore.

- The focus is on the identification of parameters affecting the H-point in CAE, and not to imitate the H-points in the physical measurements, nor to establish the relations to the SgRP.

- The legal requirement of Society of Automotive Engineers (SAE) J826 is taken into consideration, despite the fact that a newer one exist (SAE J4002), since the old one is currently referred to within VCC. Regarding legal requirements, the European and American markets are taken into consideration, since they are constituting a standard that other markets are based on.

- The primary focus area in the car is the front seat, in the driver compartment. The driver compartment is in turn limited to the areas affecting the H-point.

- Since the work is performed within VCC, the investigation is adapted to the seat parts and processes of this specific company. The SPA platform is in focus together with the car model XC90, since this is the current CAE focus of the department.

- The work is limited to 20 weeks, according to Master Thesis standards.

1.5 Outline of the Report

This chapter introduces the thesis, with background to the problem, purpose and objectives for the project, definitions of the research questions, and limitations of the project.

Chapter 2 Theoretical Framework is including theoretical information about different subjects that are considered within the thesis.

Chapter 3 Methodology of the Project is presenting the approach and the procedure of the project. It gives an overview of the used phases and steps, and describes the purpose of each phase.

Chapter 4 Execution describes in detail the performed phases in the project and the simulations that are performed to reach the results. Some results, that are considered to be needed to understand the following procedure, are also presented in this chapter.

Chapter 5 Results describes the results from the phases Sensitivity Analysis, Validity Analysis and Foam Parameter Study. In this chapter, analyses related to the results are also presented.

Chapter 6 Discussion presents reflections about the project. This is being done through discussions about the project outcome, the models and simulations, and recommendations for future research.

Chapter 7 Conclusion and Future Research concludes the thesis project and proposes research for the future, that is considered to be needed within the area.

2
Theoretical Framework

This chapter includes information about the automotive seat, Seating Reference Point, Hip-point, Torso angle, regulations, the design of experiments method, finite element theory and other topics that facilitates the understanding of the report.

2.1 Automotive Seats

The driver seat is an important part of the automotive vehicle, not only providing the driver with a seating space. It is also providing the occupant with support, protection and a comfortable seating posture. These important functions, in combination with multiple parts, safety systems and adjustments, defines why it can be considered as one complex part of the vehicle. (Kale & Dhamejani, 2015)

2.1.1 Parts of the Seat

The driver seat consists mainly of the frame, seat base, backrest, headrest, and seat track, see Figure 2.1. The frame is the part where the other components gets mounted on and the seat pan constitute a part of the frame, under the seat base. The seat base is the part where the driver sit and the backrest is supporting the driver's back. Both the seat base and the backrest consist of several components, where both parts include bolsters on the side, that facilitates the assurance of the position of the occupant when traveling. (Kale & Dhamejani, 2015)

The headrest is placed on top of the backrest, to provide the driver's head with support and safety. The seat also consists of parts connected to the seat belt and the adjustments. The seat track is basically consisting of the rails, where the seat gets mounted, and these rails often have a track angle based on what type of car model it is. The rails also enable the driver and occupant, in the front row, to move the seat forward and backwards within the vehicle. (Kale & Dhamejani, 2015)

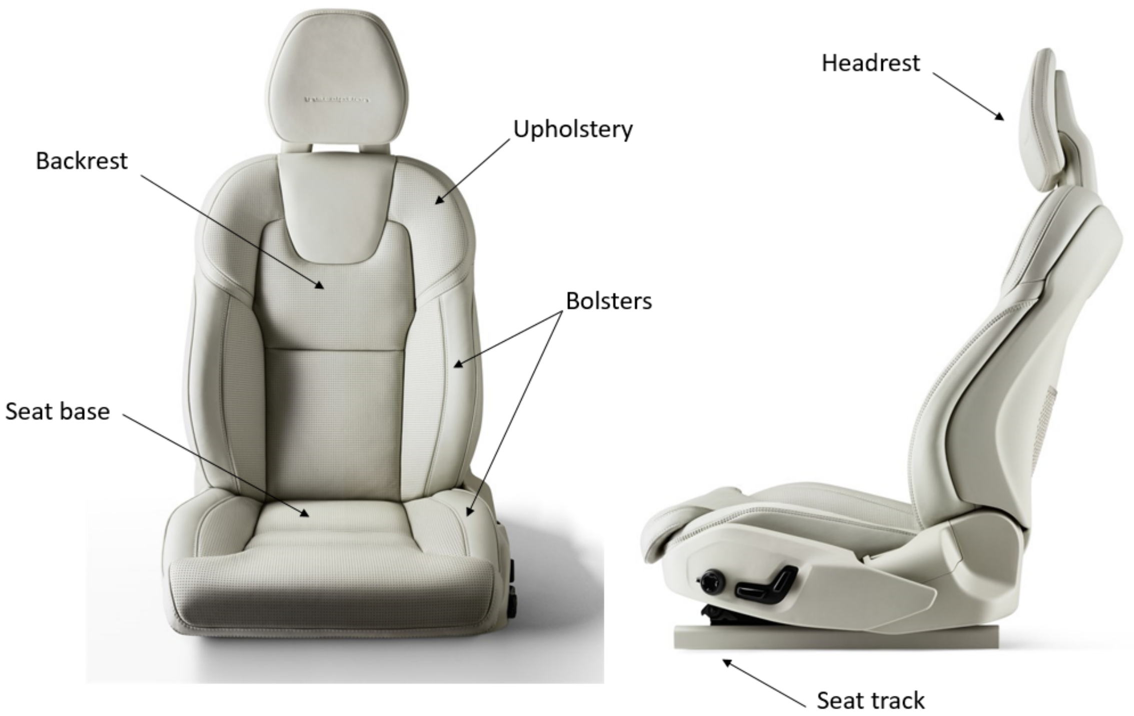

Figure 2.1: The driver seat with its parts. Photo: Volvo Cars.

2.1.1.1 Cushion Foam, Upholstery and Foam Padding

The cushion foam exists in both the seat base and the backrest, and constitute the largest volume of foam in the seat base and backrest. The upholstery, also called trim, is the surface material that is covering the cushion foam, often made of leather or textile. The upholstery can also vary between different leather and textile types for different seats, with the intention of creating aesthetic looks, without wear and stain.

The cushion foam and upholstery materials of the seat can vary from seat to seat, with different densities, hardnesses etc. A seat is often consisting of foams with different characteristics, depending on the area of the seat, e.g. a cushion foam in the backrest has one hardness, while the cushion foam in the seat base has another hardness.

Between the upholstery and the cushion foam, there is a thinner foam that is laminated, sewed, or glued to the upholstery. This thinner foam is called foam padding and it has a lower density than the cushion foam, with the intention of increasing the comfort, reduce wrinkles and cover up seams. The foam padding has different thicknesses depending on what upholstery material is used. See the layers of the upholstery, foam padding, heating mat and cushion foam in Figure 2.2. The seat also consists of upholstery attachments, used to fasten the upholstery and stretch it to a level where wrinkles disappear. Since the upholstery is pre-cut to cover a specific part of the cushion foam, it is common to cut it further when being applied to the cushion foam, in order to reduce the wrinkles further.

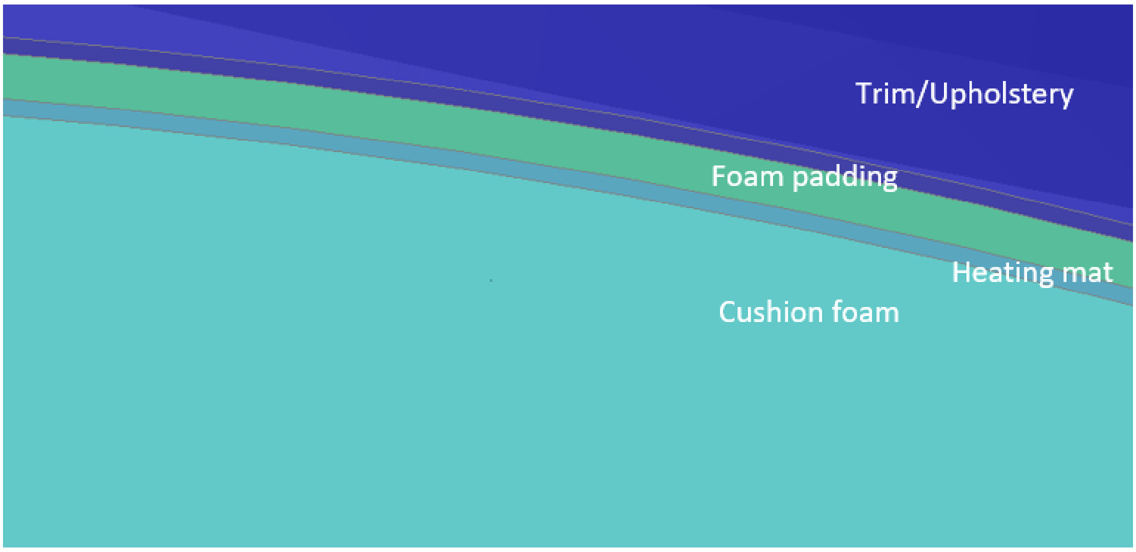

Figure 2.2: Cut section of the seat with its layers.

Within the SPA platform, there are different possible variants of the seat: the Comfort seat and the Sport seat, see Figure 2.3. The main difference between these variants are the shape, the foam, the upholstery and the foam padding. The Sport seat has a less amount of cushion foam in comparison to the Comfort seat and to compensate that, the Sport seat needs a harder cushion foam material. Both the Comfort seat and the Sport seat comes with the option of including a massage function or ventilation, which could affect the H-point, since more components gets included in the seat.

Figure 2.3: The seat types Comfort and Sport. Photo: Volvo Cars.

2.1.1.2 Seat Base

The seat base consists of different parts, and the cushion foam, upholstery and foam padding are some of them. Besides those, the seat base consists of a spring mat, heating mat, cables, plastic, and sometimes a leg extension and weight sensors. The spring mat, with metallic springs, is used to dampen the forces and reduce the vibrations experienced by the occupant. The heating mat is used to provide the occupant with heat and improved comfort. This part is often placed on top of the cushion foam, before the upholstery with foam padding gets attached. The leg extension is an option to add, which enables the occupant to adjust the depth of the seat base, which can be beneficial for a taller person that needs support for the thighs. Weight sensors can also exist in the seat base of the passenger seat, but it is mostly applied in the American market, due to local regulations. Other components like cables to the electronics, and plastic to cover and fasten components also exists within the seat base.

2.1.1.3 Backrest and Headrest

The backrest also consists of different parts. Besides the cushion foam, upholstery, and foam padding, it consist of a plastic plate, lumbar support, heating mat, headrest, and it is possible to add massage within the backrest. The plastic plate is used instead of a spring mat, which still provides the back with support, but is easier to attach components to. The lumbar support can be fixed or adjustable in four ways through inflatable cushions. The backrest comes with the option of including a massage function. The headrest is placed on top of the backrest. Other components like cables to the electronics, and plastic to cover and fasten components also exists within the backrest.

The parts of the seat and the design, are parameters affecting the positioning of the driver. However, since many parts of the car needs to be designed simultaneously, it is important to understand occupant packaging and how that affects the seating positioning and the design of the seat.

2.1.2 Occupant Packaging

Packaging is a word used in the automotive industry to describe the placement of components and systems in the vehicle space. Occupant packaging means thereby to design and place components and systems in the vehicle based on the occupant and its positioning, e.g. where the steering wheel should be placed in order for the driver to reach it from its seated position. This concept of designing the vehicle "from the inside and out" is recommended, to establish that the important factor of seating position will not be a trade-off in the end. To apply this "inside out" concept, the first step is to position the driver and other occupants, and then to design the rest of the car around them. In order to do so, a reference point of the driver's position is important to establish early in the automotive design process, called SgRP. This reference point, other definitions, and dimensions are stated within different standards and regulations for automotive vehicles. (Gkikas, 2012)

2.1.3 SgRP, H-point and Torso Angle

The SgRP is, like earlier mentioned, a reference point that is established early in the automotive design process. The SgRP is also called "a unique design H-point", and it describes where the H-point of the driver should be located to match the rest of the car design. The H-point is positioned where the occupant's thigh and torso lines intersects each other, see Figure 1.1. (Gkikas, 2012)

A human could be imagined of having two H-points, one right and one left, with different coordinates. However, despite the fact that a human has two hips and that adjustable seats could have many different H-points within the travel path, there is only one H-point and one SgRP for each seat. The H-point is the average of the the right and left H-point coordinates, being positioned in the middle of the manikin, and not on the actual hip. See Figure 2.4.

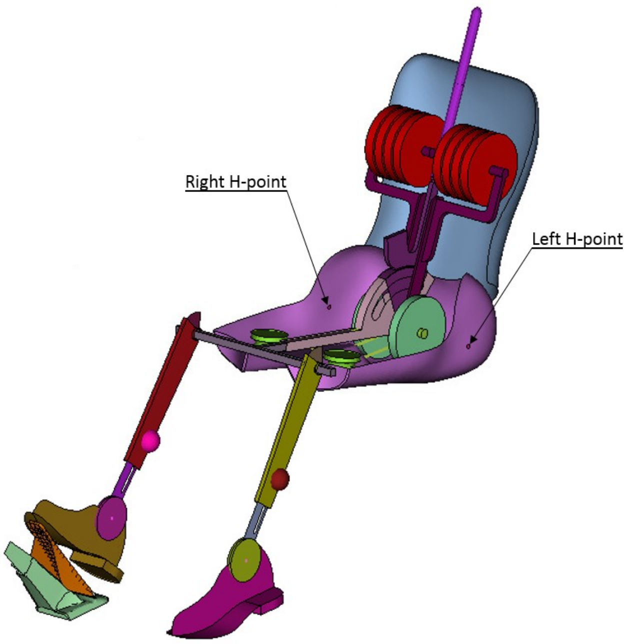

Figure 2.4: Right and left H-point.

Both the H-point and the SgRP are measured in coordinates (X, Y, Z), in relation to the designed vehicle structure, see Figure 2.5. The H-point and SgRP are depending much on the type of vehicle, e.g it is lower in Z-direction in a Sedan, than in a SUV. (SAE International, 2009)

Figure 2.5: The three dimensional (3D) reference system. Photo: Volvo Cars.

The H-point can be compared to the SgRP when the H-point has been measured physically, with a positioned manikin in a physical seat. In the optimal case, the SgRP and the measured H-point would appear on the exact same coordinates. However, this is a rare occasion, since variations always appear in both processes and parts. Due to the deviation that will appear between the SgRP and the H-point, tolerances of what is approved are stated within different regulations and standards. The regulations and standards are also the ones including definitions, such as the H-point and the SgRP.

The Torso angle is a term that is related to the H-point and it describes basically the angle of the back. The Torso angle reflects the posture imposed by the backrest on the Hip-point Machine (HPM). The Torso angle gets measured between the torso line of the HPM and the vertical line, crossing the H-point. The definition of the Torso angle can be seen in Figure 2.6. Since the Torso angle is affecting the posture of the occupant, it is measured every time the H-point coordinates are measured. (SAE International, 2015)

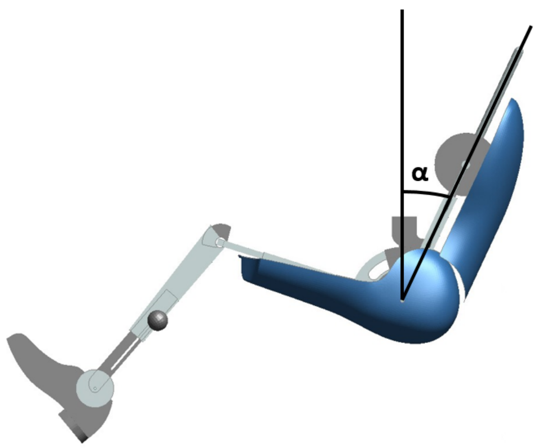

Figure 2.6: The definition of the Torso angle.

2.1.4 Standards and Regulations

There are different standards and regulations for different geographical markets.

2.1.4.1 SAE International

The Society of Automotive Engineers (SAE) International is a global association, with technical experts in industries such as aerospace, automotive, and commercial-vehicle industries. The SAE is recognized as the world's largest automotive standards setting body and has published more than 1 600 technical standards and recommended practices for passenger cars. SAE Standards are mainly focused on safety, quality, and the effectiveness of the products and services in the global, automotive engineering industry. (SAE International, 2017)

Many of the SAE standards are used or based on when creating and developing regulations, for different countries and markets.

- **SAE J826 - Devices for Use in Defining and Measuring Vehicle Seating Accommodation**. This is the regulation that VCC is following regarding how to position the manikin, that is representing the human body. The standard specifies a two dimensional (2D) template and a 3D HPM that is used to define and measure the accommodation in vehicle seats. The procedures of how the HPM should be positioned is also described, in order to measure the H-point. (SAE International, 2015)

- **SAE J1100 - Motor Vehicle Dimensions**. This is a recommended practice standard that is used within VCC to define the most relevant points and dimensions of the vehicle interior. For example, it is defining the H-point, the SgRP, the Torso angle and other important definitions of the driver. Dimensions are also defined, such as leg room, shoulder room, knee clearance and other dimensions that are of interest within the occupant packaging, in the vehicle interior. (SAE International, 2009)

In long term, there are several other SAE standards that in turn affects the seating position and H-point, for example the SAE J4004 that describes the process of defining the SgRP.

2.1.4.2 Federal Motor Vehicle Safety Standards

Federal Motor Vehicle Safety Standards (FMVSS) are United States (U.S) federal regulations, that manufacturers of motor vehicles should follow to ensure that the minimum safety performance requirements of the vehicles are established. These FMVSS are developed and enforced by the National Highway Traffic Safety Administration (NHTSA), that is an executive part of the U.S government.(National Highway Traffic Safety Administration, 1999)

The FMVSS are, like the SAE standards, often used as a base when creating and developing regulations, for different countries and markets.

- **FMVSS 208 - Occupant Crash Protection**. This standard is set to reduce the number of fatalities and severity of injuries to occupants, involved in frontal crashes. It affects the automotive seat and the positioning of the driver through its design, due to the fact that the relation between the occupant and the roof can be critical in a frontal crash, when the head of the driver risk of colliding with the roof before being embraced by the airbag. A seat design where the occupant is positioned too high could therefore be colliding with this standard. (National Highway Traffic Safety Administration, 1999)

2.1.4.3 United Nations Economic Commission for Europe

The United Nations Economic Commission for Europe (UNECE or ECE) is regional commission to encourage economic cooperation between the members. Besides countries in Europe, it includes Canada, the Central Asian republics, Israel and the United States of America. A part of the UNECE is to create a system of regulations for facilitating international trade, for vehicle design. (United Nations Economic Commision for Europe, 2016)

- **ECE R17 - Seats, Seat anchorages, Head restraints**. This is one of the regulations from the UNECE, that is affecting the design of the seats. In this regulation, it is among other things stated that the H-point is allowed to vary maximum +/- 25 mm from the SgRP, to conform with the rest of the car of occupant packaging. This regulation is also defining the manikin of a 76 kg man, the same as in SAE J826, but with 50 percentile legs instead of 95 percentile legs, that are used within SAE J826. This regulation is also describing how the procedure of measuring the H-point in physical seats should be performed for this shorter manikin, which is sometimes differing from the procedure of the taller manikin, in SAE J826. (United Nations Economic Commision for Europe, 2014)

2.2 Design of Experiments

Design of Experiments (DOE) is a statistical method used to evaluate parameters influence on an output and their correlation with each other. An input parameter in a process is a source of variability for the output of the model, and once the input variables for the model are identified, a statistically-based experiment can be designed to determine the influence of each factor on the output. (Davim, 2016)

2.2.1 Full Factorial Design

To identify all of the multi-factor interaction effects, besides the main effect of each factors influence on the output, a 'Full Factorial Design' can be used. The method is in general practical to use when the experiments are inexpensive. If k is the number of parameters and m is the number of levels, then the number of trials in a Full Factorial Design is m^k. (Ulrich & Eppinger, 2012)

To determine the main effect of a parameter, i.e. how much the parameter influences the output, a common approach is to take a low value and a high value for each parameter and then construct a matrix for which combinations are tested.

Table 2.1: A Full Factorial Design for three parameters.

I	A	B	C	y_n
1	1	1	1	y_1
2	-1	1	1	y_2
3	1	-1	1	y_3
4	-1	-1	1	y_4
5	1	1	-1	y_5
6	-1	1	-1	y_6
7	1	-1	-1	y_7
8	-1	-1	-1	y_8

In Table 2.1, a Full Factorial Design is presented for parameters A, B, and C with two levels. To test all possible combinations, it takes m^k runs, where $k = 3$ and $m = 2$ which gives $2^3 = 8$ runs. The I column represents the number of the run, A, B and C the parameters, and y_n the output. The -1 and 1 corresponds to low and high values of the parameters respectively.

2.2.2 Fractional Factorial Design

The Fractional Factorial Design uses, as the name implies, only a fraction of the combinations of the Full Factorial Design. The interactions are confounded with other interactions to increase the efficiency of the DOE. The balance is still maintained for this layout within the experimental plan, i.e. each parameter is tested the same number of times, at each level. (Ulrich & Eppinger, 2012)

2.2.3 Orthogonal Array Design

The Orthogonal Array Design is the smallest Fractional Factorial Design where it is still possible to identify the main effects of each factor. The benefit of an Orthogonal Array Design is its efficiency, while the drawback is that the main effects are confounded with many interaction effects. (Ulrich & Eppinger, 2012)

2.2.4 Main Effect

The main effect of a parameter is how much the change of a parameter influences the system. To calculate the main effect of a parameter, the outputs where the parameter is having the high level is subtracted by the outputs where the parameter is having the low levels and then divided by half the number of runs, where the number of runs is represented by n. Equation 2.1 illustrates how the main effect for parameter A is calculated. (Montgomery & Runger, 2014)

$$A = \frac{y_1 + y_3 + y_5 + y_7 - y_2 - y_4 - y_6 - y_8}{\frac{n}{2}} \tag{2.1}$$

The numerator here is called the contrast, as can be seen in Equation 2.1, $Contrast_A$ can be defined as shown in Equation 2.2.

$$Contrast_A = y_1 + y_3 + y_5 + y_7 - y_2 - y_4 - y_6 - y_8 \tag{2.2}$$

2.2.5 Interaction Effect

An interaction effect is how multiple parameters together influence the system. Interaction effects are calculated in the same way as the *main effect*, described in section 2.2.4 above, but with different "high" and "low" alternatives. Consider the example of having a two parameter interaction, then the "high" alternatives are when both parameters are either low or high and the "low" alternatives are when one of the parameters are low and the other one is high. The interaction effect then becomes an expression of how the parameters in question influences the system together. The contrast of AB from Table 2.1 would be calculated as shown in Equation 2.3. (Montgomery & Runger, 2014)

$$Contrast_A = y_1 + y_4 + y_5 + y_8 - y_2 - y_3 - y_6 - y_7 \tag{2.3}$$

2.2.6 Sum of Squares

The contrast shown in Equation 2.2 can also be used to calculate the sum of squares for the parameter in question. The sum of squares will show more clearly what parameter that affect the system than the main effects, since the sum of squares shows how much it affects the system, regardless of a sign. The equation for calculation of the sum of squares can be seen in Equation 2.4. (Montgomery & Runger, 2014)

$$A = \frac{(Contrast_A)^2}{n} \tag{2.4}$$

2.2.7 Normal Probability Plot

A normal probability plot is used as a graphical method to determine whether a sample of data conforms to a hypothesized distribution, as described by Montgomery and Runger (2014). The normal probability is used to identify deviations from the normal, which in the DOE can be used to identify significantly influential parameters. To plot the main effects, using a normal probability plot, the main effects are sorted and then plotted against the standardized normal scores z_j, where z_j is defined according to Equation 2.5. (Montgomery & Runger, 2014)

$$z_j = \frac{j - 0.5}{n} \tag{2.5}$$

2.3 Finite Element Theory

The Finite Element Method (FEM) is a numerical method that seeks an approximated solution of the distribution of some field variable, e.g. the displacement in a case of structural analysis, the electrical charge in electrical analysis etc. FEM works by dividing the problem domain into small segments called elements. Each element is then subjected to physical principles and laws, and is then tied together with the surrounding elements to describe the distribution of the field in the entirety of the geometry in question. The process leads to a set of algebraic equations for the entire system that can be solved to yield the field variable. (Liu & Quek, 2013)

2.3.1 Solid Elements

A solid element is a 3D element and is describing the field variables fully, in terms of all three physical coordinates (X, Y and Z). It can therefore be considered as the most general of all finite elements. Each node in the element have three translational degrees of freedom, which enables the element to move in all three directions in space. The solid element model can be used to model any kind of physical object, like plates or beams etc. However, the process can be unnecessarily tedious and significantly more demanding on computer resources, so whenever possible, simpler models like shell, beam or truss should be used to reduce computation time. (Liu & Quek, 2013)

2.3.2 Shell Elements

Shell elements are a simplification of a part of a plate- or shell-like structure. It is using only a shell as a structure, making it a 2D element, and then the 2D element is assigned with a thickness. This is a less complex model than the 3D solid element, which in turn reduces the computational demands significantly, whilst it still retain a representative accuracy. (Liu & Quek, 2013)

2.3.3 Processing

When the model is ready for simulation, it is sent to a processor-software that solves the discretized system of equations. There are different solvers available, that works differently.

2.3.3.1 LS-DYNA

LS-DYNA is a processing software that can be used to solve multi-physics problems for solid mechanics, heat transfer and fluid dynamics (Livermore Software, 2002). LS-DYNA is useful for its ability to solve highly nonlinear finite element analysis (Livermore Software, 2017b).

2.3.3.2 MAT83

In finite element simulations, modeling of physical materials can be a challenge when the material in question is nonlinear in nature, as foams are. For foams in particular, there are different approaches for modeling. There is a macro-structural approach where the foam is considered as a continuum. Another way is to use a micro-structural approach, where the foam is considered as a cubic model where standard beam theories and solid-fluid interactions are used to describe the foam material. In LS-DYNA there is a material model called MAT83, that is used to describe foams. The approach used with MAT83 is to consider the Poisson's ratio of the foam to be equal to zero, which eliminates coupling between material axes. This in turn leads to a one-dimensional material law, where uni-axial curves given from experiments can be used. (Serifi, Hirth, Matthaei, & Müllerschön, 2013)

2.3.3.3 MAT34

Since woven fabric is in general a highly nonlinear and non-isotropic material, it creates difficulties when modeling the material. MAT34 is a fabric material model that has stress map functionality. This material model uses mapping of fiber stresses to corresponding warp and weft fiber strain points within the domain of the simulation. (Thomas & Ehle, 2015)

2.3.4 Pre-Processing

To prepare a model for simulation, using FEM, there are broadly four steps that need to be performed (Liu & Quek, 2013).

- Modeling of the geometry
- Meshing
- Specification of material property
- Specification of boundary, initial, and loading conditions

The first step in simulating a problem, using FEM, is to model the geometry. This can be done in a Computer Aided Design (CAD) -software or the finite element software itself. After the geometry is defined, the next step is to discretize the geometry or "mesh it", to divide up the geometry into small elements. How the elements are divided is an important factor that can affect the outcome and its accuracy.

The third step is to define the right material to the right parts, since in a problem there might be different materials to analyze. In composite structures there can even be multiple materials. The last part is to define the boundaries, the initial, and the loading conditions for the simulation, which is all done using the pre-processing software.

2.3.4.1 ANSA

ANSA is a pre-processing tool used for Finite Element Analysis (FEA), which can be used to create models for crash, durability, noise, vibration and harshness, and computational fluid dynamics amongst else. (BETA CAE Systems, 2016)

2.3.4.2 PRIMER

PRIMER is a tool designed to be capable of reading, processing and writing out all keywords and any information that LS-DYNA uses with no exceptions. The software also includes several special features such as e.g. occupant positioning. (Oasys Ltd, 2017)

2.3.4.3 JSEAT

JSEAT designer is a plugin-tool for PRIMER used for seat design, as stated by Livermore Software (2017a). JSEAT is useful for preparing models for H-point measurements but have other uses as well.

2.3.5 Post-Processing

When the processor software has solved the equations, visualization of the results remains, this is where the post-processor software is used. The way the results are visualized can differ, but for a solid mechanics problem the results are displayed as displacement of affected regions and perhaps color coding of for example the stresses experienced throughout the regions. (Liu & Quek, 2013)

2.3.5.1 META

Meta is a multi-purpose post-processor that can be used within various CAE disciplines. It has support for different processors used in FEM as well as Computational Fluid Dynamics. (BETA CAE Systems, 2017)

2.4 Summary of Theoretical Framework

The automotive seat is an important part of the automotive vehicle, consisting of many different parts. Regulations for the markets are setting standards about what manikin that can be used and how the H-point should be measured. In the thesis, the method of Design of Experiments (DOE) have been frequently used, and many different terms that are important to understand, such as main effect and Full Factorial Design are explained in this chapter. The method of Finite Element Method (FEM) is used as a base in Computed-Aided Engineering (CAE), and in this chapter some terms are explained, together with some of the used software of this thesis.

3

Methodology of Project

This chapter presents the approach and procedure for carrying out this project and the purposes behind the actions.

3.1 Project Process

Considering that this is not a new product development project, the phases were adapted to the specific thesis and purpose. The project was divided into five main phases: Problem Exploration, Sensitivity Analysis, Validity Analysis, Foam Parameter Study and Final Recommendations, according to Figure 3.1.

Figure 3.1: Process of the used methodology in the project.

3.1.1 Problem Exploration

The purpose of this phase was to explore the problem, through different approaches. To understand the seat, to understand the methods of how the physical H-point measurements are performed, to understand the methods of predicting the H-point through CAE, and to understand what parameters affects the H-point in a larger context, was covered in this phase. The Problem Exploration phase was divided into six steps.

- **Step 1: Expert Consultation**. To collect existing knowledge and experience about subsystems and sub problems, experts can be consulted (Ulrich & Eppinger, 2012). This was performed to receive company knowledge about the specific product and problems.

- **Step 2: Research of Literature**. To collect information, literature are considered as fertile sources (Ulrich & Eppinger, 2012). Published literature, such as journals and articles are often used and the internet is considered to be a suitable start of literature search (Ulrich & Eppinger, 2012). This step was performed in order to learn more about general things, like definitions and regulations.

- **Step 3: Problem Formulation**. By formulating and clarifying the problem, a general understanding can be gained (Ulrich & Eppinger, 2012). This was performed in order to understand the background of the problem in detail.

- **Step 4: Observations of Existing Methods**. By watching a task being performed, important details can be revealed (Ulrich & Eppinger, 2012). Observations can be completely passive, but can also be including work next to the operator (Ulrich & Eppinger, 2012). This was performed in order to understand how the H-points are measured physically and how they are predicted with CAE.

- **Step 5: Identification of Causes to the Problem**. A root-cause-analysis, also called Ishikawa diagram, can be used to identify the causes to a problem (Bergman, B. and Klefsjö, B., 2010). This was performed in order to understand what parameters in general could affect the H-point.

- **Step 6: Identification of Design Parameters to Investigate**. This stage was performed in order to know what parameters to consider in the Sensitivity Analysis, which was partly based on the previous stage of identifying causes.

3.1.2 Sensitivity Analysis

The purpose of a Sensitivity Analysis is to evaluate what sources of input influences the output of a model and to what extent, where a model is an interpretation or simplification of an existing system (Saltelli et al., 2008). The Sensitivity Analysis was performed to investigate parameters of the seat to find out what influences the output of the position of the H-point.

The approach of the Sensitivity Analysis was based on the DOE. This was a recommended approach for simulations, according to multiple sources, especially together with the purpose of finding out what parameters affect the output the most. It was also recommended by theory to perform a Screening if having many parameters, to screen out the parameters with less effect on the output and reduce the number of simulations. This was considered to be applicable on this thesis, which caused the implementation of having a Screening in the approach. (Banks, 1998) (Ulrich & Eppinger, 2012)

However, since a Screening would only tell what parameters that could affect the output the most and not tell anything about the interactions among the parameters, a more detailed investigation was planned for the parameters continuing from the Screening. This step was called Full Factorial Design, since it describes the DOE setup for the more detailed investigation. The Sensitivity Analysis was divided into four steps.

- **Step 1: Selection of Alternatives to the Parameters**. Before performing the Sensitivity Analysis, it was necessary to decide how to represent the selected parameters in the model and what alternatives of the parameter to test.

- **Step 2: Finite Element Modeling of the Seats**. Based on the previous stage, the seats could be prepared for the simulations. The models were based on a given seat model and additions were made to this. The models were prepared in the software ANSA and PRIMER. When the seat models were ready, the floor and manikin was positioned through the software PRIMER and JSEAT.

- **Step 3: Screening**. When the seat models were ready, the simulations could be performed, through a Screening. The reason for performing a Screening, was to remove the parameters that did not seem to influence the H-point and to further investigate in the parameters influencing the H-point the most.

- **Step 4: Full Factorial Design**. When the Screening was performed and the amount of parameters had been reduced, the Full Factorial Design could be performed. The intention of the Full Factorial Design was to investigate more in detail the parameters that were found to be influencing the H-point the most and to investigate the interaction between the parameters.

3.1.3 Validity Analysis

A Validity Analysis can be used to verify the simulation models and validate the domain of applicability (Banks, 1998). The purpose of this phase was to evaluate the validity of the results from the Sensitivity Analysis, to investigate the domain of applicability of different seat types. The CAE models also got reflected upon. The Validity Analysis was divided into three steps.

- **Step 1: Comparison Between Comfort and Sport Seat**. The purpose of this step was to investigate whether the results from the Sensitivity Analysis could be applied on another seat type than Comfort.

- **Step 2: Validation of the Relations Between X, Z and Torso angle**. The purpose of this step was to investigate whether the results from the Sensitivity Analysis, regarding the relations between X, Z and Torso angle, were reasonable.

- **Step 3: Uncertainties in the Model Content**. An additional evaluation of the executed Sensitivity Analysis was performed with the purpose of reflecting about why the analysis of the thesis might be or not be accurate enough to trust.

3.1.4 Foam Parameter Study

To explore the second purpose of the thesis, to suggest a suitable material combination to use in CAE, different seats with different materials were simulated. This was needed, since earlier investigations by the department at VCC had shown that depending on what types of foams that are used within the simulations, a variance of H-point could be found. The Foam Parameter Study was divided into three steps.

- **Step 1: Selection of Parameters and Alternatives**. To decide what parameters to investigate and how to limit the study was considered as important, in order to make a small study that could give valuable results, but still not be time consuming.

- **Step 2: Execution of the Simulations**. Ones the selected parameters and alternatives had been selected, the setups could be prepared and simulated with the positioned manikin.

- **Step 3: Comparison of the Results and the Existing Data**. By comparing the results of the Foam Parameter Study with physical measured H-points the result could be analyzed and the most suitable material combination could be selected.

3.1.5 Final Recommendations

The purpose of this phase was to establish recommendations based on the findings from the Sensitivity Analysis, the Validity Analysis, and the Foam Parameter Study. These recommendations were about what parameters to consider in the seat to move the H-point in a desired direction. In this phase there were no clear stages, like for previous phases.

3.2 Summary of Methodology of Project

The chapter described the process of the project and the purpose of them, with the five main phases in focus: Problem Exploration, Sensitivity Analysis, Validity Analysis, Foam Parameter Study, and Final Recommendations. The Problem Exploration was performed to understand the topic. The Sensitivity Analysis was performed to identify what parameters that affect the coordinates of the H-point. The Validity Analysis was performed to verify the accuracy of the result from the Sensitivity Analysis and to evaluate if the same results of one seat type could be applied on another seat type. The Foam Parameter Study was performed to investigate in what materials to use in the CAE models for different hardnesses of the foam, to provide the CAE models with suitable representations and with less variations in H-point coordinates. The Final Recommendations was the phase where the output of the thesis was summarized into recommendations regarding the H-point.

4
Execution

This chapter presents in detail how the project has been carried out, to reach the results. Note that some part results are also published within this chapter, that are contributing to the continued execution.

4.1 Problem Exploration

The Problem Exploration phase could be divided into different activities; Expert Consultation, Research of Literature, Problem Formulation, Observations of Existing Methods, Identifying Causes to the Problem and Identifying Design Parameters of the Seat Affecting the H-point. When the output from these activities were considered adequate, the problem was considered to be explored and prerequisites for the Sensitivity Analysis were considered to be executed.

4.1.1 Expert Consultation

In order to gain further understanding of the seat, several consultations were given by the employees within the department. A general introduction was given at first, to gain knowledge about the whole seat, and then employees with different expertise were contacted for more detailed information. The meetings with the employees of different expertises could be considered as knowledge gathering introductions and not as interviews, as the purpose of the meetings were to get to know the parts included in the seat even better. The output of this step is presented in the Theoretical Framework.

4.1.2 Research of Literature

To gain knowledge about the automotive seats, the H-point, SgRP, regulations and standards were considered as essential parts of the problem exploration. Therefore, literature was used from the Internet, books and articles. The output of this step is presented in the Theoretical Framework.

4.1.3 Problem Formulation

In order to understand the problem and get an overall view, a formulation of the problem was created. The problem formulation could also be seen as a more detailed continuation of the background to the thesis and could create an understanding for the need of the thesis.

4.1.3.1 Formulation

In the product development process of a seat, it is important to confirm that the H-point is positioned within the tolerances for the SgRP, to match the rest of the design of the car. However, the H-point is not available to measure physically until a physical seat exists, which is in later stages of the development process. If the H-point exceeds the accepted tolerances, then a redesign of the seat has to be made.

To avoid these time demanding and costly loops, the need for using a virtual method and predicting the H-point is high. By being able to predict the H-point, before a physical seat exists, it would be possible to identify the position of the H-point in an earlier development stage and act more rapidly regarding a possible redesign, see Figure 4.1.

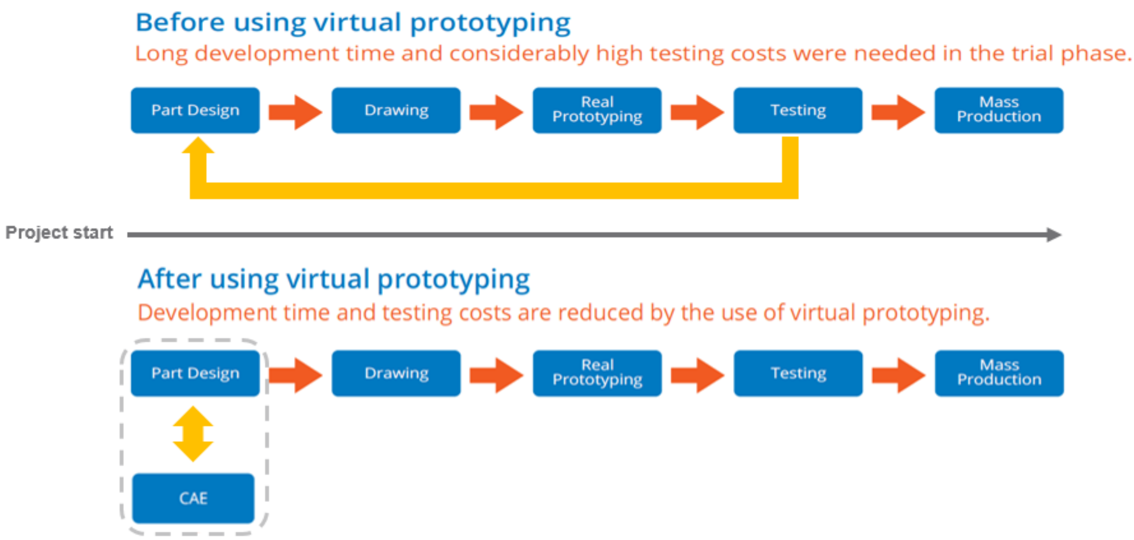

Figure 4.1: The contribution of CAE to the product development process.

Within VCC, the development of such a method has begun, with the intention of implementing it within the product development process within a near future. Before the implementation can begin, it is important to understand the relation between a CAE predicted H-point and a physically measured H-point.

Results have shown that the H-points vary from one seat to another (for both CAE H-points and physical ones), see Figure 4.2, and it is of interest to gather more knowledge about what parameters are causing the variation of H-points for the seats, and if those are individual for each seat type or if a general formula for all seats can be stated.

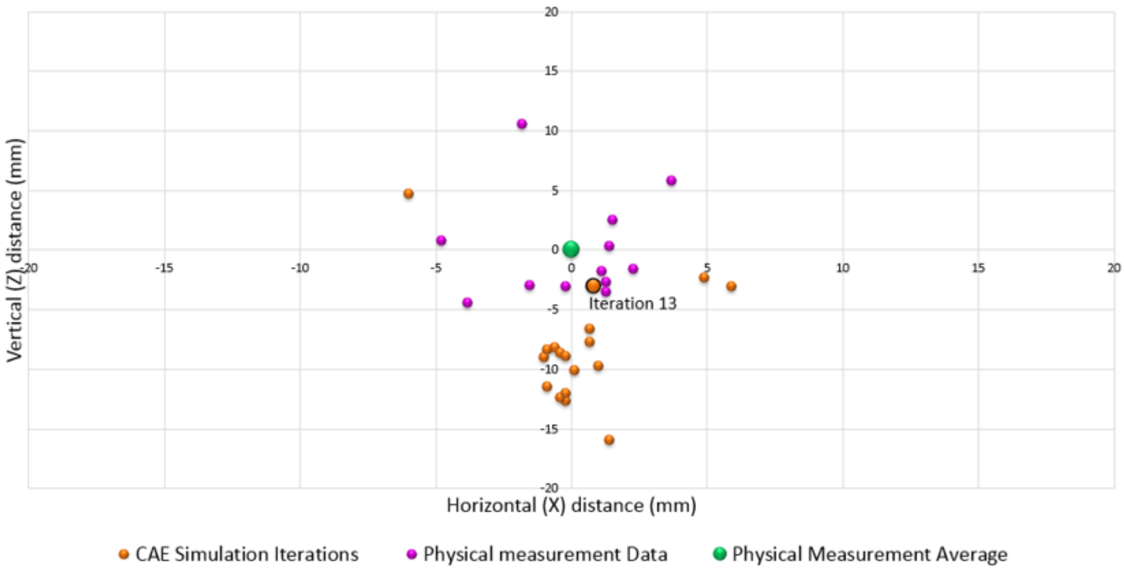

Figure 4.2: Variation of H-points.

Additionally, a design trend of sloping A-pillars has been found in the automotive industry, with lower roof, which minimizes the space between the driver and the windshield. The minimized space can cause serious damages in a possible crash, since there is an increased risk of the driver's head to hit the roof/windshield, before it hits the airbag. The regulation of FMVSS 208 states that the driver should meet the injury criteria in a possible crash, which sets higher demands on the position of the driver, and thereby the position of the H-point.

According to the regulation ECE R17, the tolerance of the H-point deviation from the SgRP is +/- 25 mm, according to Figure 4.3.

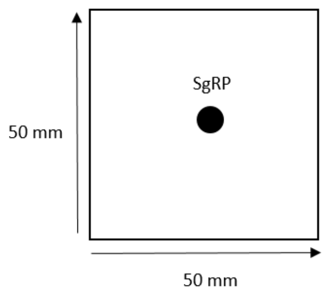

Figure 4.3: SgRP and the tolerance of H-point deviation, according to ECE R17.

However, due to the circumstances mentioned above, VCC has decreased their tolerance of allowed deviation between H-point and SgRP. This sets higher demands on the seats in the automotive industry and further knowledge about what parameters that are affecting the H-point in different directions, to primarily lower the H-point in Z-direction. By lowering the H-point in Z-direction, the compromise between safety of the driver and the sloping A-pillars can be avoided.

4.1.4 Observations of Existing Methods

In order to understand the current methods of measuring the H-point physically, an observation had to be done. Since data of physical measurements of the H-point is collected from both a department at VCC and by a subcontractor, both were being visited. The existing CAE method of predicting H-points was also investigated. To understand this method further, observations of employees using the method and literature were helpful.

4.1.4.1 Observation of Physically Measured H-points

A more detailed observation was performed within VCC, by observing the employees performing twelve tests, of three different seats, placed in two different cars, with two different manikins. The three seats were of the same type, only with manufacturing variances, and the cars were the S90/V90 platform and the XC90 platform, where the latter was of higher interest for this project.

During the observation at VCC, the employees were positioning the manikins (R17 and J826), and measuring the H-point with a probe, see Figure 4.4. The process was based on the procedure from the standards of SAE J826 and the agreement with the subcontractor. The result of the performed physical H-point measurements during the observation can be found in Appendix A.

Figure 4.4: Observation of physical measurement of H-point, at VCC.

The observation at the subcontractor consisted of a visit. However, the observation from the visit is not presented, due to confidential information.

The observations showed, however, that the H-point is sensitive and could differ around two millimeters for the different seats, even though they are supposed to be identical. The result of the physical measured H-points, in Appendix A, also showed that the R17 manikin had a tendency of getting a higher H-point in Z-direction, in comparison to the J826 manikin.

4.1.4.2 Observation of CAE Predicted H-points

VCC is using a LS-DYNA software based tool to position the manikin and predict the H-point of a seat. The seat models are prepared using ANSA and PRIMER software. The manikin is then positioned according to the SAE J826 procedure with contacts and boundary conditions through the script. For the R17 manikin, the software JSEAT is used for positioning the manikin. One simulation of positioning the manikin takes approximately 30 hours and the H-point result can then be shown in coordinates, together with the Torso angle.

The CAE prediction method was also compared at this stage to the physical observations, to facilitate the Validity Analysis in a later phase. The result showed that the CAE prediction method and the physical measurement of H-points were having some differences, that could affect the result of comparing them to each other. However, those differences are not either stated here, due to being confidential.

4.1.5 Identification of Causes to the Problem

To understand the causes to why the H-point vary with different coordinates for different seats, an overview model of this was created. This was created with an Ishikawa diagram, also known as a root-cause-analysis, a fish-bone diagram or a cause-and-effect diagram, see Figure 4.5. The Ishikawa diagram was divided into four main causes;

- **Measurement process** - The observations showed clearly that the measurement process of how to measure the H-point has impact on the position.

  The physically measurements are impacted by the human factor, such as who is performing the measurements. Precision of the tools, the probe, the manikin and the temperature can also have an impact here. The differences between the physical measurements and the CAE prediction, found in the observation, could also show that the H-point varies based on the measurement process.

- **Manufacturing** - The manufacturing of seats is also one aspect that is affecting the H-point.

  This could be because of the tolerances, part variations and process variations in the manufacturing process. Even if one seat is designed to be having a foam with a certain hardness, a possible variance can make seats different, even if they have the same design and should be having identical H-points. This is something that could be seen in the observation, where the three seats got H-points that differed around two millimeters, despite that they had the same design and should theoretically have the same H-point coordinates. See Appendix A, for the results of the physically measured H-points of the observation.

- **Design process** - The design process is also one aspect that affects the H-point.

  Depending on what components are added, what materials are being chosen, what shape and what placement the parts are designed to have, could affect the H-point. Depending on the market the seat is designed for, the regulations can also be different, which means that for some markets some components may need to be included, which could affect the origin height of the seat and thereby the H-point.

- **Physical parts** - The physical parts themselves and their alternatives affect the H-point. The foam is one of the main contributors, being deflected by the manikin or driver. Hardnesses, densities, shape of foam etc. will influence the deflection of the foam. Other physical parts that may influence are the trim/upholstery, foam padding, etc.

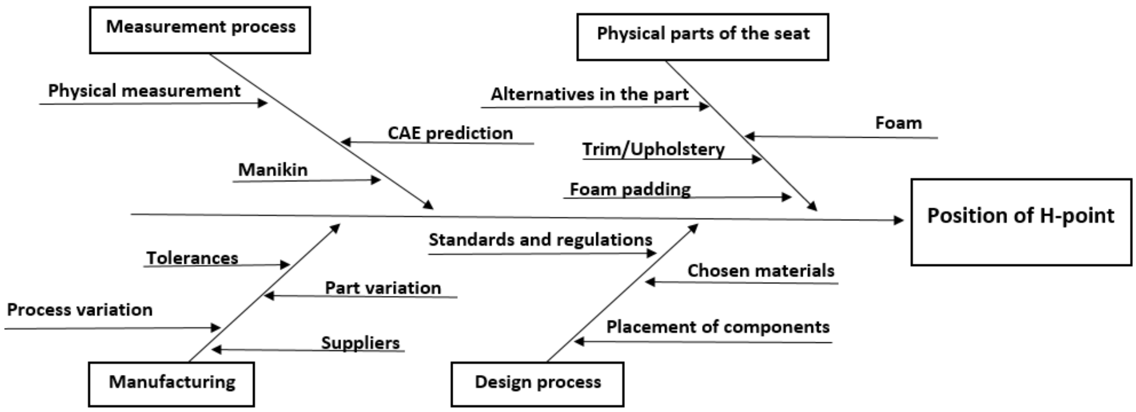

Figure 4.5: Ishikawa diagram of causes to the H-point variation.

As can be seen in Figure 4.5, there are many contributing aspects as to why the H-point can vary. This is essential to know when moving forward with the project.

4.1.6 Identification of Design Parameters to Investigate

Amongst all the contributing factors to the H-point variations, the physical parts and the alternatives in the seat were of highest interest to investigate within this thesis. The parameter identification process, could be seen as a funnel, see Figure 4.6.

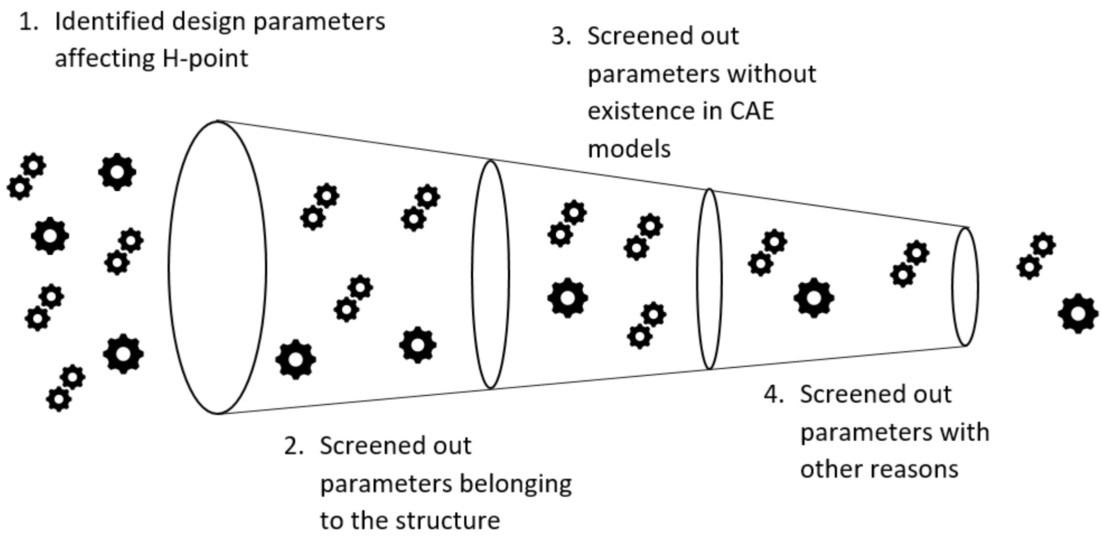

Figure 4.6: Funnel of the process to identify parameters for further investigation.

First, the possible parameters of interest were identified into a list, see Table 4.1. Then, some parameters were screened out because they belonged to the structure (see limitations for the project). After that, some parameters were screened out because they did not exist in the CAE model of the seat and thereby were not possible to test. The last step was to eliminate parameters that had other reasons for not being further investigated.

Table 4.1: Parameters to investigate and reasons for screening out parameters.

Parameters	Status	Structure	Not in CAE	Other reason
Foam type	**NO**			**X**
Shape of foam	**YES**			
Cushion width/ Insert width	**NO**			**X**
Cushion depth/ Bolster height	**NO**			**X**
Bolster insert radius	**NO**			**X**
Foam thickness	**YES**			
Foam hardness	**YES**			
Angle of seating plane	**NO**	X		
Foam damping properties	**NO**			**X**
Foam density	**YES**			
Upholstery	**YES**			
Seat variant: Sport/Comfort	**YES**			
Seat variant: Leg extension	**YES**			
Seat variant: Massage	**NO**		**X**	
Recliner	**NO**	**X**		
Frame and spring behaviour	**NO**	**X**		
Number of upholstery attachments	**NO**		**X**	
Shape of upholstery attachments	**NO**		**X**	
Foam padding hardness	**YES**			
Foam padding density	**NO**			**X**
Weight sensors: OWS & SBR	**NO**			**X**
Rails	**NO**	**X**		
Cutting specifications	**NO**		**X**	
Sewing tolerances	**NO**		**X**	
Manikins: J826 & R17	**YES**			

The parameters that were not further investigated for other reasons were:

- Foam type - In the CAE model, different materials could be assigned to the parts in the seat. However, in order to enable to experiment with the hardness and the density, the foam types got limited to a single one, and were thereby not included for further investigation. The type of foam was considered later in the Foam Parameter Study.

- Cushion width/Insert width, Cushion depth/Bolster height, Bolster insert radius - All of these parameters were considered to be about the shape of the cushion, which was included in the investigation as another parameter, and therefore these parameters were not investigated separately.

- Foam damping properties - These parameters were describing the foams, with properties like Young's modulus, elasticity etc. However, these were not investigated individually, but were considered to be included in the material changes when changing from one material to another.

- Foam padding density - This parameter was not investigated, since it only existed materials with higher densities than what is used today.

- Weight sensors: OWS and SBR - The Occupant Weight Sensor (OWS) and Seat Belt Reminder (SBR) exist within the passenger seat, but not in the driver seat, which could then be excluded because of the limitations of the thesis.

The parameters that were identified to be further investigated was: Shape of cushion, Foam thickness, Foam hardness, Foam density, Upholstery, Seat variant: Leg extension or not, Foam padding hardness, and Different manikins: J826 and R17. The seat variant of Sport was not available in the CAE when the Screening would be performed, so the Shape of cushion replaced that parameter temporarily, until the Sport seat would be available in CAE and be compared to the Comfort seat. The next section presents what each parameter represents and how they vary within the simulations.

4.2 Sensitivity Analysis

To identify the significant parameters and their influence on the H-point, a Sensitivity Analysis was performed with the primary focus on the displacement of the H-point in the Z-direction.

4.2.1 Selection of Alternatives to the Parameters

The previous sections described how the selection of parameters to investigate were made. However, each parameter had different amounts of alternatives, e.g. the parameter of upholstery had four different alternatives existing in CAE that could be investigated in, but the parameter of manikin did only have two alternatives.

To facilitate the Sensitivity Analysis, and use DOE as a method, it was decided to choose two alternatives from each parameter, with one high and one low value, see Table 4.2. Even though this decision was considered to limit the output in understanding what alternatives of the parameters that would affect the H-point, it would still provide information about what parameters that influence the H-point the most.

Table 4.2: Parameters included in the Screening and their alternatives.

	Parameters	Alternative -1	Alternative +1
A	Foam hardness area 1	Low hardness	High hardness
B	Foam hardness area 2	Low hardness	High hardness
C	Foam hardness area 3	Low hardness	High hardness
D	Foam hardness area 4	Low hardness	High hardness
E	Foam hardness area 5	Low hardness	High hardness
F	Upholstery (Trim)	Leather	Textile
G	Leg extension	No leg extension	With leg extension
H	Manikin	R17	J826
I	Shape of foam	No added thickness	Added thickness
J	Foam padding hardness	Low hardness	High hardness
K	Foam density area 1	Low density	High density
L	Foam density area 2	Low density	High density
M	Foam density area 3	Low density	High density
N	Foam density area 4	Low density	High density
O	Foam density area 5	Low density	High density

Foam hardness/density

When selecting which type of foam to use, the material properties that were taken into consideration were the hardness of the foam and the density of the foam. When designing a seat, it is preferable to not use the same type of foam for the whole seat, for example it is desirable to make the bolsters slightly more rigid to keep the body in place in the seat, while the cushion in the seat base would be made less rigid in order to provide more comfort.

For this Sensitivity Analysis, it was chosen to divide the seat into five different sections, see Figure 4.7, and let these sections vary individually in both hardness and density. To get a clear view of how much each section would influence the H-point they were all chosen to vary in the same range, between the low and high hardness, and between the low and high density, according to Table 4.2.

The chosen ranges of hardness and density were based on the hardnesses and densities that the seat was designed for. The five areas of the seat resulted in ten parameters (A-E and K-O), five for the hardness and five for the density, according Table 4.2. Area 1 was the middle part of the backrest and Area 2 was the bolsters of the back. Area 3 was the middle part of the cushion, Area 4 was the bolsters of the cushion, and Area 5 was the leg extension part of the cushion.

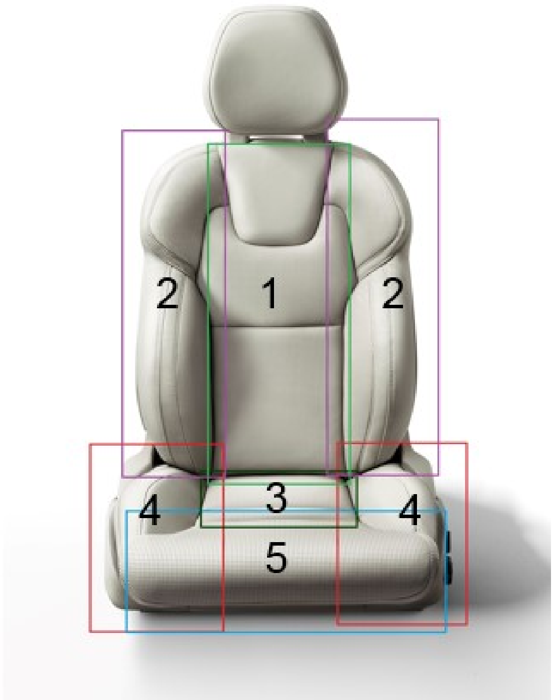

Figure 4.7: The divided areas of the seat. Photo: Volvo Cars.

Foam thickness/Shape of cushion

Since foam varies in size, depending on what type of seat it is, it was chosen as a parameter to test how much the size variance influence the H-point. This was done by raising the height of the foam in the cushion by 8 mm in the Z-direction and expanding the backrest by 8 mm in X-direction. This was represented by the parameter I, in Table 4.2. The alternative in the Screening was to have this additional thickness or to not add the thickness.

Foam padding hardness

The earlier mentioned foam padding, that exists between the upholstery and the cushion foam, is also made of foam. Since the theory states that this foam has a significantly lower density than the other foams, it got a lower density than the cushion foams. This padding is thin in comparison to the main foam, and a hypothesis was therefore that it would affect the H-point less, but in order to represent the real seat as much as possible, it was included in the Sensitivity Analysis. The hardness of the foam padding was represented by parameter J, in Table 4.2.

Upholstery

The upholstery of the seat comes in a variety of choices, and one type of textile upholstery and one type of leather upholstery was investigated in the Sensitivity Analysis, since the textile upholstery has a much higher stiffness than the leather upholstery. The upholstery is represented in the finite element model as a shell element, sharing nodes with the underlying solid foam material as a 'bottom surface'. Since the foam padding, under the upholstery, is thicker for textile types than for leather types, the thickness of the foam padding have been included within this parameter as well. The foam padding of the textile was assigned with a thickness of six millimeters, while the leather type has been assigned with four millimeters. The parameter of upholstery (with its foam padding thickness) was represented by parameter F, in Table 4.2.

Manikin

The manikin had the alternative of being the R17 manikin or the J826 manikin. The choice of having these two manikins was because they are the alternatives that are used within the department and are adapted to the markets of interest. The two manikins are having the same weight, but the R17 manikin has shorter legs and represents a 50 percentile person, while the J826 manikin has longer legs and represents a 95 percentile person. Besides the leg length, there were also some differences between the process of positioning the manikins and measuring the H-point of the manikins, which was discovered when observing the existing methods in the problem exploration phase. The manikin was represented as parameter H, in Table 4.2.

Leg extension

In the seat, there is an option to choose whether to include a leg extension or not. Since earlier investigations by the department at VCC have shown that the leg extension is a part that the manikin does not touch in the model, it was of interest to investigate whether this option influences the H-point at all. The leg extension was represented by parameter G, in Table 4.2.

4.2.2 Finite Element Modeling of the Seats

When the project started, two seat models that had been used for crash simulations amongst else, were available as a basis for the simulations. The difference between the two models was that one of them included a leg extension, while the other one did not. These two models also differed in a way that one of them was from a later stage of the development process, resulting in higher quality mesh. However, both models were missing representation for some parts, and to make a more realistic representation of the models, two major changes were made.

The foam padding and heating mat did not exist in the CAE models and representations of these were made in this step. Even though the foam padding and the heating mat did not add much thickness, they could theoretically add some rigidity to the foam, which was why the decision to create a representation of these in the model was made.

The modeling of these components was done in ANSA, and for simplicity both the foam padding and the heating mat were created as solid 3D meshes. To create these meshes, a simple extrude was made from the surface of the foam parts. The foam padding also changed thickness depending on which upholstery was used, meant that more than one model had to be created.

The way the upholstery is attached to the structure in a real seat, is not represented in the finite element model. However, the upholstery was modeled, using shell mesh and sharing nodes with the surface layer of the foam padding. This represented it as if the fabric was glued to the surface of the foam. When using shell mesh, the most commonly used procedure is to have the shell element as a mid surface, where the thickness is applied equally in both directions. However, for the shell to be able to share nodes with the solid 3D mesh that represents the foam, the option of adding thickness in only one direction in was used.

The materials used for the foams were of a material type called MAT83, which is described in section 2.3.3.2. The upholstery was modeled with the material type MAT34, which is described in section 2.3.3.3. The material chosen for the heating mat was a MAT83 material as well, which was not an accurate representation, but due to time constraints it was considered to be close enough.

After the materials had been assigned, the manikin was positioned using a script. This script applied the load case according to the SAE or ECE regulations. The whole seat was considered as deformable during the simulation, except for the seat track.

4.2.3 Screening

The Screening was performed to remove non-significant parameters from the list, since each parameter would double the amount of simulations required. The Screening was performed using an Orthogonal Array Design with 15 parameters and 16 runs, where the setup for the matrix can be seen in Table B.1, in Appendix B. The downside of using the Orthogonal Array Design was that the main effect of each parameter was confounded with other parameters. However, since an Orthogonal Array Design was the smallest Fractional Factorial Design that still identified the main effects of each factors, it was considered as an appropriate method for a Screening method, with the intention of selecting which parameters to proceed with. (Ulrich & Eppinger, 2012)

One simulation, or run, was performed with the following steps:

1. **Assign the selected materials.** In order to choose specific hardnesses and densities, specific materials were selected. These were assigned to the seat through the software PRIMER, with respect to the combinations in Table B.1.

2. **Position the selected manikin to the seat**. Depending on the manikin, if using R17 or J826, different softwares were used. JSEAT was used for the R17 manikin and PRIMER was used for the J826 manikin. The reason for

using different software was because of the predefined methods in the software of positioning the manikins.

3. **Start the simulation**. Once the correct combination of seat and manikin was created, the simulation needed to be started. This was done by using a cluster. Each simulation could last between 30 and 70 hours.

4. **Control the stability of the simulated model**. This was performed to make sure that the result would be approved and trustworthy. If the model was considered to be instable, the process got repeated from stage 1. The control consisted of multiple steps, following a checklist. See Appendix C. The checklist included for example, to make sure that the Z-coordinates were stabilized when reaching the end of the simulation.

5. **Get the result**. When a simulation was finished, the H-point coordinates and Torso angle could be received, through the script that was mentioned earlier.

Once the 16 seats had been simulated with the previous mentioned steps, the result from the whole Screening could be analyzed and a decision for how to continue with the Full Factorial Design could be made.

4.2.3.1 Result of Screening

The results showed H-points between +8,7 mm to +29,5 mm, in Z-direction, see Table B.2, in Appendix B.

However, to identify what parameters that were affecting, the main effects needed to be calculated, which was done in Matlab. This code could be seen in Appendix D. In the Matlab code, the Z-coordinates of the H-points were inserted and the main effects were calculated as shown in the Theoretical Framework. When each main effect was calculated, a normal probability plot could be displayed, see Figure 4.8. The parameters deviating from the normal probability line would be the ones affecting the H-point the most, in Z-direction.

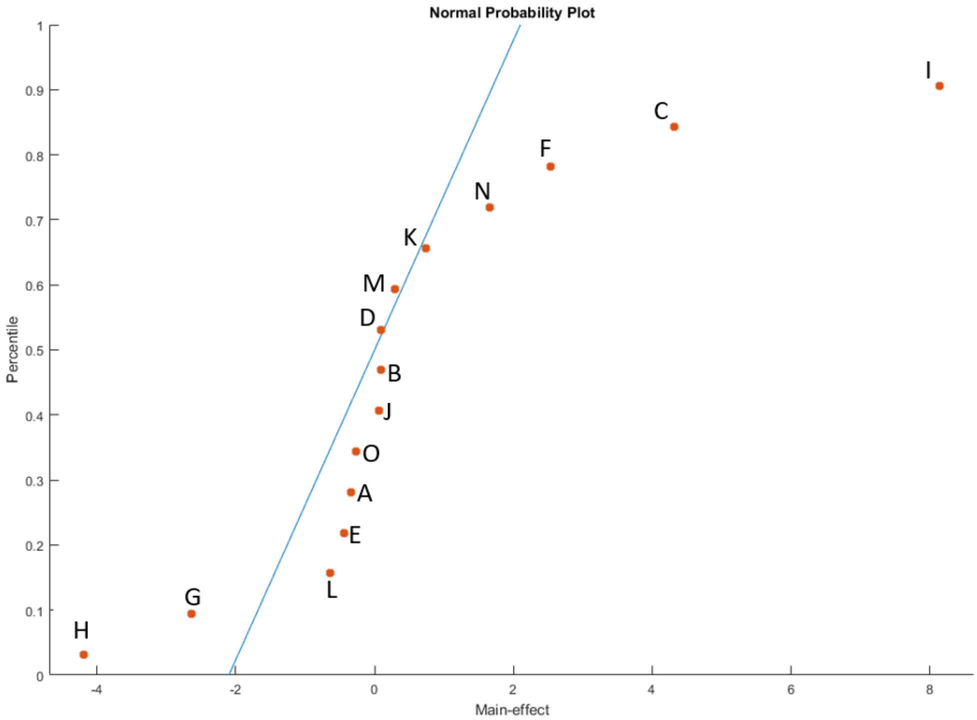

Figure 4.8: Result from the Screening - Normal probability plot with main effects.

Even though the main effects in the normal probability plot could display what parameters that affected the most, they were also displayed in Table 4.3 to compare the parameters against each other. To rank the parameters main effects regardless of signs, the sum of squares for the main effects were calculated.

Table 4.3: Result from the Screening - Main effects and Sum of squares.

Parameter	Main effect	Sum of squares
A - Foam hardness area 1	-0.3375	0.4556
B - Foam hardness area 2	0.0875	0.0306
C - Foam hardness area 3	4.3125	74.3906
D - Foam hardness area 4	0.0875	0.0306
E - Foam hardness area 5	-0.4375	0.7656
F - Upholstery (Trim)	2.5375	25.7556
G - Leg extension	-2.6375	27.8256
H - Manikin	-4.1875	70.1406
I - Shape of foam	8.1375	264.8756
J - Foam padding hardness	0.0625	0.0156
K - Foam density area 1	0.7375	2.1756
L - Foam density area 2	-0.6375	1.6256
M - Foam density area 3	0.2875	0.3306
N - Foam density area 4	1.6625	11.0556
O - Foam density area 5	-0.2625	0.2756

The result showed that the parameters with largest influence on the H-point, without any ranking, were:

- Parameter C - Foam hardness of area 3 (seat base insert)
- Parameter F - Upholstery (Trim)
- Parameter G - Leg extension
- Parameter H - Manikin
- Parameter I - Shape of foam
- Parameter N - Foam density of area 4 (seat base bolsters)

Shape of foam was the parameter with largest influence and Foam density of area 4 was the one with less influence, out of the six mentioned. This could be seen in Table 4.3, where the main effects deviating from 0 were contributing the most. This got even more clear for sum of squares, where the highest sum of square was affecting the H-point the most, like mentioned in the Theoretical Framework.

However, for continuation to the Full Factorial Design it was decided to not include all six parameters, since that would result in 64 simulations and that was considered as too many in relation to the time allocated to the step. Since the parameter I (Shape of foam) was affecting the H-point the most, it was decided to use that parameter in the Validity Analysis instead of including it to the Full Factorial Design. By using the 'Shape of foam'-parameter in the Validity Analysis, a separate study could be performed to compare a seat variant of Comfort and compare it to a seat variant of Sport, and use the results to validate the results of this Sensitivity Analysis.

Therefore, the parameters that continued to the Full Factorial Design, and the more detailed investigation of parameters affecting the H-point, were:

- Parameter C - Foam hardness of area 3
- Parameter F - Upholstery (Trim)
- Parameter G - Leg extension
- Parameter H - Manikin
- Parameter N - Foam density of area 4

4.2.4 Full Factorial Design

The Full Factorial Design could be considered as the real investigation of the parameters, while the Screening was performing the pre-investigation of screening out unimportant factors. The main difference between the Screening and the Full Factorial Design, as mentioned in the Theoretical Framework, was the accuracy of the result. The Screening showed the main effects for each parameter, but with some confounded results with the other parameters. The choice of having a Full Factorial Design resulted in a more accurate DOE, in comparison to the Orthogonal Array Design that the Screening was based on. By using this type of DOE, the Full Factorial Design was not supposed to include any confounded results and interaction effects among the parameters could be analyzed.

The limitation of two alternatives for each parameter were kept, to get clear results but still keep it simple. However, one of the parameters got changed alternatives for the Full Factorial Design. Foam hardness of area 3 was the only parameter that got changed alternatives, in comparison to the Screening. In the Screening, there was a bigger difference between the low hardness and the high hardness. For the Full Factorial Design, the alternatives got closer to the actual used hardness of today in the seat. The other parameters kept their earlier alternatives based on the fact that no other alternatives existed or that the best alternatives were already considered, see Table 4.4.

Table 4.4: Parameters included in the Full Factorial Design and their alternatives.

	Parameters	Alternative -1	Alternative +1
A	Leg extension	No leg extension	With leg extension
B	Foam hardness area 3	Low hardness	High hardness
C	Upholstery (Trim)	Leather	Textile
D	Foam density area 4	Low density	High density
E	Manikin	R17	J826

Another difference between the Screening and the Full Factorial Design was that the parameters that were screened out from the Screening, were now kept constant at the standard values, used within the seat today.

Since the Full Factorial Design was more thorough than the Screening, the number of runs/simulations increased even though the number of parameters decreased from the Screening. The Full Factorial Design consisted of 32 simulations, see Table E.1 in Appendix E, with respect to the five chosen parameters, in Table 4.4.

Like mentioned earlier, the interactions between the parameters were investigated in the Full Factorial Design, which made the normal probability plot show 31 main effects, instead of five. Those 31 interactions represented all possible combinations between the five parameters, including 2-, 3-, 4- and 5-way interactions.

The simulations for the Full Factorial Design were performed with the earlier described approach of the Screening, with everything from assigning the selected materials, to control the stability of the simulated model, and receive results about the H-point. However, the result was investigated in further detail for the Full Factorial Design simulations, in Z-direction, X-direction and Torso angle.

Matlab was once again used to calculate the main effects, sum of squares, and normal probability plot for the parameters and interactions. The code was using the same base as for the Screening, but were adapted to the amount of parameters and interactions. See Appendix D. The result of the Full Factorial Design can be seen in the chapter Results, where it is analyzed as well.

4.3 Validity Analysis

To evaluate the validity of the results from the Sensitivity Analysis, an analysis was performed. The analysis included comparisons between a Comfort seat and a Sport seat, and some uncertainties with the simulations were reflected upon, where the Sensitivity Analysis was evaluated.

4.3.1 Comparison Between Comfort and Sport Seat

The comparison between the Comfort seat and the Sport seat was based on a DOE, with an Orthogonal Array Design. It consisted of seven parameters, see Table 4.5, with eight runs according to Table F.1 in Appendix F. The reason for not having 15 parameters like in the Screening was that it was not possible due to model restrictions. The choice of having a Orthogonal Array Design made it possible to investigate many parameters, but with the risk of having confounded results.

The seven chosen parameters were all parameters that had been used before in the Sensitivity Analysis. The reason for choosing parameters that had been used before was to compare the results from the Sensitivity Analysis with this study and also compare it against the Sport seat. The parameters were consciously not just the parameters affecting the H-point from the Full Factorial Design, since it was of interest to compare both affecting and not affecting parameters.

Table 4.5: Parameters included in the Validity Analysis and their alternatives.

	Parameter	Alternative -1	Alternative +1
A	Foam hardness area 1	Low hardness	High hardness
B	Foam hardness area 2	Low hardness	High hardness
C	Foam hardness area 3	Low hardness	High hardness
D	Foam hardness area 4	Low hardness	High hardness
E	Foam hardness area 5	Low hardness	High hardness
F	Upholstery	Leather	Textile
G	Manikin	J826	R17

Since this setup was being performed for both the Comfort seat and the Sport seat, it resulted in 16 runs. However, since the Screening used relatively large differences for the hardnesses, while the hardnesses in the Full Factorial Design were adapted to imitate the ones used in the seat today, it was considered to be of interest to compare them both.

This resulted in four eight-run Orthogonal Array Designs, two for Comfort and two for Sport, where two were having large differences in hardness and the other two were imitating the reality, with small differences in hardness. Table 4.6 shows how it resulted in 32 simulations.

Table 4.6: The four times eight run-configuration of the Validity Analysis.

	Comfort	Sport
Large difference in hardness	8 runs	8 runs
Small difference in hardness	8 runs	8 runs

The alternatives for parameter F (Upholstery) and G (Manikin) were the same through the four groups, while the alternatives of parameter A-E (Foam hardnesses) varied based on having the large difference in hardness alternatives or the small difference in hardness alternatives.

Even though the result of the Validity Analysis would be partially confounded, it was considered beneficial to analyze the four different groups with each other and to have seven parameters, rather than using a Full Factorial Design with three or four parameters. If a Full Factorial Design would have been selected for four parameters and four groups, it would have resulted in 64 simulations, which was not an alternative with respect to the simulation time and time assigned to the phase.

The hypothesis to be tested here was whether the same parameters had the same effect on both seats. The result of the Validity Analysis can be seen in the chapter Results, where it is analyzed as well.

4.3.2 Relations Between X, Z and Torso Angle

In order to evaluate the validity of the relations in the Sensitivity Analysis, the H-points of the Comfort seat and Sport seat were compared against each other. By performing these comparisons, the relations could be confirmed or not for the different types of seats.

The relations got compared to each other by displaying all of the 32 H-points in different plots. For each investigated relation, two plots were displayed; one for the H-points from the Comfort seat and one for the H-points from the Sport seat. This resulted in six different plots: two for the X vs. Z, another two for X vs. Torso angle, and the last two for Z vs. Torso angle.

By plotting these six plots of the H-points, it could be visualized whether the same relations could be stated as for the Full Factorial Design and whether the same relations could be applied on both the Comfort seat and the Sport seat.

4.3.3 Uncertainties in the Model Content

In order to evaluate the validity of the Sensitivity Analysis, the simulations were reflected upon. The reflections were mainly based on the CAE model representations and the procedure of predicting the H-point in CAE. The reflections were supposed to state what was uncertain in the simulations and how that affected the validity.

4.4 Foam Parameter Study

The second focus of the thesis was to perform a Foam Parameter Study. The intention of the study was to decide what foam materials to combine to represent the reality the best and match the CAE H-points with the physically measured H-points. By selecting the most suitable combination, the variation in H-points based on the materials could be minimized.

The Foam Parameter Study was focused on the hardness of the foam and limited to the Comfort seat. It was also primary focused on the Z-direction. The study was performed by changing the foam materials assigned to the seat. The setup was once again based on DOE, through a Full Factorial Design. The reason for choosing a Full Factorial Design, was that the hardness was in focus and the Screening had earlier showed that only a few areas affected the H-point, regarding the hardness. Few areas resulted in few parameters, which resulted in the possibility of performing a Full Factorial Design without unrealistic many runs. Additionally, since the purpose was to find the best material combination and not the parameters affecting the H-point, it was considered as necessary to perform a Full Factorial Design.

4.4.1 Selection of Parameters and Alternatives

The parameters in this setup were selected based on the Screening results, where the areas with the hardnesses seemed to impact the H-point the most were selected. Since the bolsters in the back and the cushion part (area 2 and 4) did not seem to influence the H-point, regarding the hardness, according to the Screening, these were not further investigated in the Foam Parameter Study. The areas of interest were instead area 1 - the middle part of the backrest, 3 - the middle part of the cushion and 5 - the leg extension part of the cushion.

Since this was considered to be the second focus of the thesis and less time was allocated to this area, in comparison to the Sensitivity Analysis, a simplified study was performed. To simplify the study, each area was assigned with two alternatives like in previous simulations. The alternatives were adapted to the hardness for each area in the seat of today, so that for example: Area 1 is used to have a hardness of 4 kPa in the seat of today, so the two alternatives are two different foam types where both have 4 kPa. Note that this was only an example and the hardness of 4 kPa is not the correct one.

The chosen alternatives can be seen in Table 4.7. Due to confidential information, the name of the foam types and their hardnesses have not been displayed. Type 1, 2 and 3 means that there are three different types of foam. Type 2.1 and Type 2.2 are of the same foam type, but with two different hardnesses. Since parameter B and C are both parts of the cushion and have the same original hardness in the seat of today, they are having the same alternatives in this Foam Parameter Study.

Table 4.7: Parameters included in the Foam Parameter Study.

	Parameters	Alternative -1	Alternative +1
A	Backframe insert	Type 1	Type 2.1
B	Cushion insert	Type 3	Type 2.2
C	Cushion leg extension	Type 3	Type 2.2

4.4.2 Execution of the Simulations

Unlike the Screening and Full Factorial Design, the Foam Parameter Study was not about identifying what parameters that are affecting the H-point. The focus was instead to compare the seat combinations (simulations) with physical data to identify the combination that was the most suitable one to use in CAE. To select the best one with respect to different upholsteries, the simulations were repeated for three different upholstery's - one textile type and two different leather types. This resulted in 24 simulations, that can be seen in Table G.1, in Appendix G.

4.4.3 Comparison of the Results and the Existing Data

After running the simulations, the result was compared to existing data of physical measured H-points. Since the Foam Parameter Study was divided based on the upholstery, the existing data got sorted out based on the upholstery. The physical measured H-points with the same upholstery got an average, which resulted in three averages. The simulations could then be compared to the average and the results could show what combination of foam types that would be appropriate to use, in order to get as close as possible to the average of the selected upholstery.

4.5 Final Recommendations

The Final Recommendations were stated after the Full Factorial Design, Validity Analysis and Foam Parameter Study was performed and analyzed, since the result of these were used as a base. The Final Recommendations included two types of recommendations; one part regarding the parameters affecting the H-point, and another regarding recommended future work. The recommendations regarding the parameters are stated in the chapter Results, while the recommendations regarding future work are stated in the discussion.

4.6 Summary of Execution

This chapter includes the procedure of how the phases of the thesis have been executed; Problem Exploration, Sensitivity Analysis, Validity Analysis, Foam Parameter Study and Final Recommendations. In comparison to the previous chapter, Methodology of the Project, that was more of an overview of the approach, this chapter explains in further detail the executed steps.

5
Results

This chapter states the result of the Full Factorial Design, Validity Analysis, and Foam Parameter Study, and analyzes it further. The recommendations that the analyzes resulted in, are also stated within this chapter.

5.1 Result of Full Factorial Design

The 32 simulations of the Full Factorial Design resulted in H-points, see Table E.2 in Appendix E, between: -2,2 and +17,5 mm in Z-direction, 31,5 and 42,5 mm in X-direction, and 5,2 and 6,9 degrees in Torso angle.

5.1.1 Parameters Affecting the H-point

To analyze the parameters affecting the H-point and the directions, the Z-coordinate, X-coordinate and Torso angle were analyzed separately.

5.1.1.1 Z-coordinate

The result showed that six parameters seemed to affect the H-point to a larger extent than the others, in the Z-direction. The parameters with the most influence on the H-point in Z-direction, can be seen through the main effects and sum of squares, in Table 5.1, and in the normal probability plot, in Figure 5.1.

Table 5.1: The main effects and sum of squares of the parameters, in Z-direction.

Parameter	Main effects	Sum of squares
C - Upholstery	6,5765	691,9977
E - Manikin	5,8328	544,3378
AC - Leg extension and Upholstery	3,369	181,6039
B - Foam hardnesss area 3	1,7305	47,912
A - Leg extension	1,4422	33,2767
D - Foam density area 4	-1,2239	23,9679

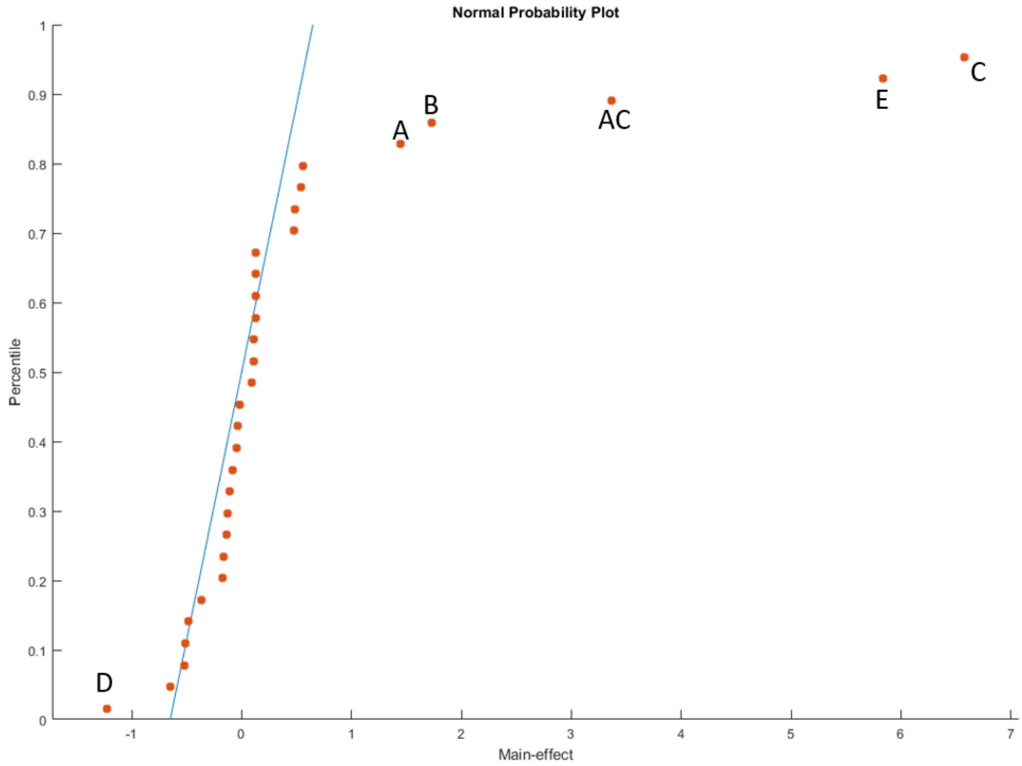

Figure 5.1: Normal probability plot with main effects for Z-direction.

The parameters C, E and AC were clearly affecting the H-point in Z-direction more than the parameters B, A and D, according to the main effects and sum of squares.

5.1.1.2 X-coordinate

The result showed that six parameters seemed to affect the H-point to a larger extent than the others, in the X-direction. This could be seen in the Table of main effects and sum of squares, Table 5.2, and in the normal probability plot, in Figure 5.2

Table 5.2: The main effects and sum of squares of the parameters, in X-direction.

Parameter	Main effects	Sum of squares
C - Upholstery	- 4,9779	396,4638
A - Leg extension	- 3,6758	216,19
AC - Leg extension and Upholstery	- 1,8574	55,199
E - Manikin	- 1,3931	31,051
AE - Leg extension and Manikin	1,1992	23,0074
ACE - Leg extension, Upholstery and Manikin	1,1676	21,8126

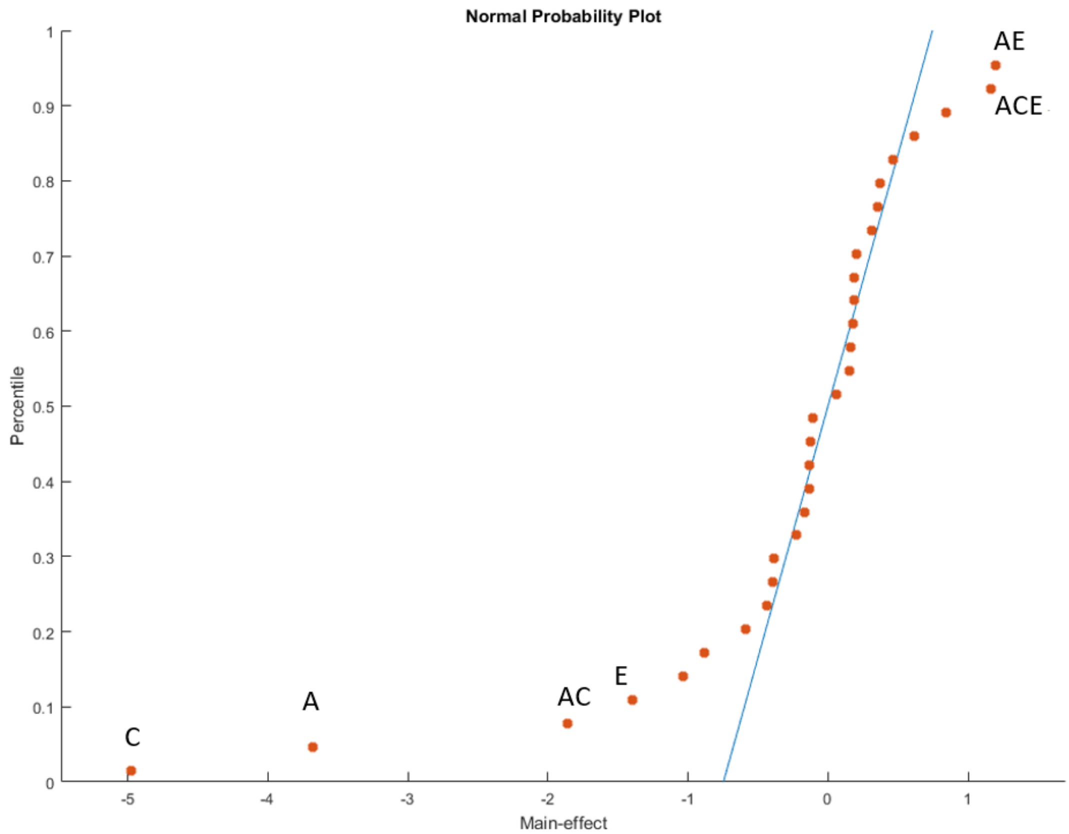

Figure 5.2: Normal probability plot with main effects for X-direction.

Parameter C and A were clearly affecting the H-point in X-direction more than parameter AC, E, AE and ACE, according to the main effects and sum of squares.

5.1.1.3 Torso Angle

The result showed that three parameters seemed to affect the H-point to a larger extent than the others, in Torso angle. This could be seen in the Table of main effects and sum of squares, Table 5.3, and in the normal probability plot, in Figure 5.3.

Table 5.3: The main effects and sum of squares of the parameters, for Torso angle.

Parameters	Main effects	Sum of squares
E - Manikin	0,524	4,3932
A - Leg extension	0,50563	4,0905
C - Upholstery	0,30287	1,4677

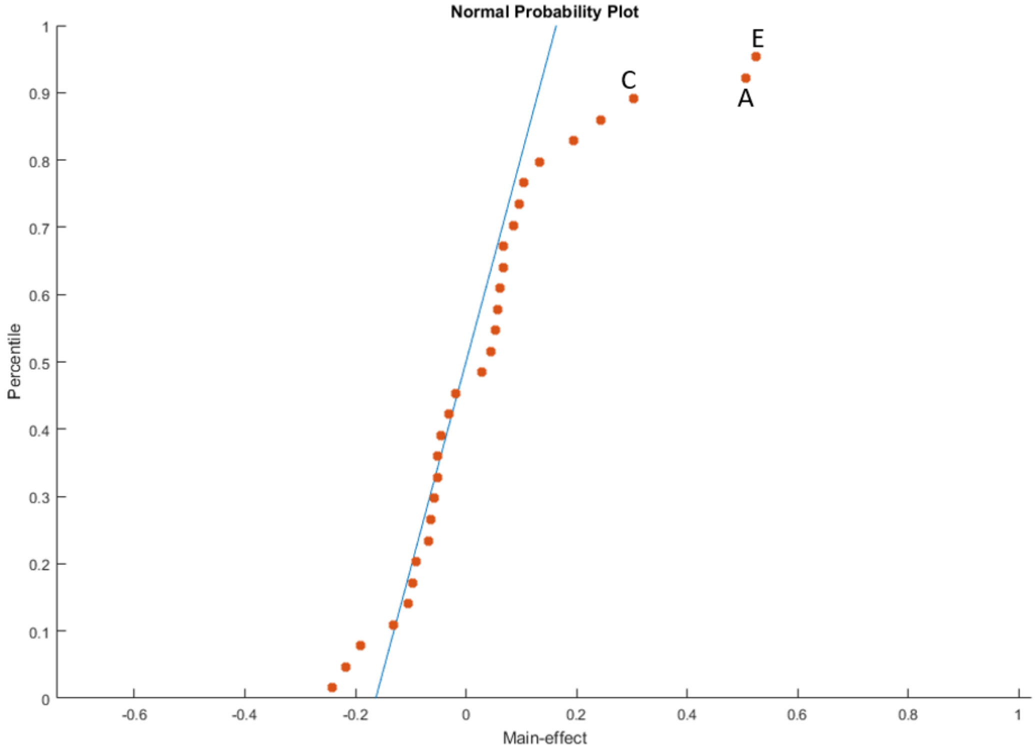

Figure 5.3: Normal probability plot with main effects for the Torso angle.

Parameter E and A were clearly affecting the Torso angle more than parameter C, according to the main effects and sum of squares.

5.1.2 Relations Between X, Z and Torso Angle

Since it was discovered that many of the same parameters seemed to affect the H-point in Z-direction, X-direction and Torso angle, it was of interest to investigate the relation between these three.

5.1.2.1 X vs Z direction

The X-coordinates were compared to the Z-coordinates from the results of the Full Factorial Design. By comparing them against each other, Figure 5.4 could be displayed.

The plot, in Figure 5.4, shows clearly a relation between the X and Z coordinates. Since a lower coordinate on X means that the manikin is positioned further forward, the relation show that if the manikin is positioned further forward in the seat, the H-point seem to increase in Z-coordinate.

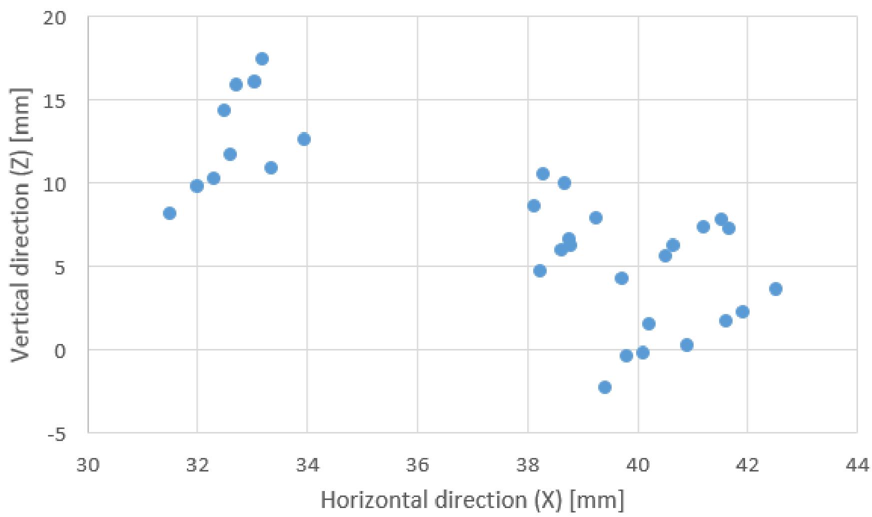

Figure 5.4: The relation between X and Z for the Full Factorial Design.

However, it can also be seen that this does not apply individual levels linearly, e.g. if the X-coordinate decreases with one millimeter, this does not mean that the Z-coordinate increase with one millimeter - or increase at all. This means that the X and Z have a relation, but that it is more global than local. This can be seen in the two groups in the plot, in Figure 5.4, with a gap separating them in X-direction. The group with the lower X-coordinates are clearly higher positioned in Z-direction, than the other group.

5.1.2.2 X vs Torso Angle

The X-coordinates were compared to the Torso angles from the results of the Full Factorial Design. By comparing them against each other, Figure 5.5 could be displayed.

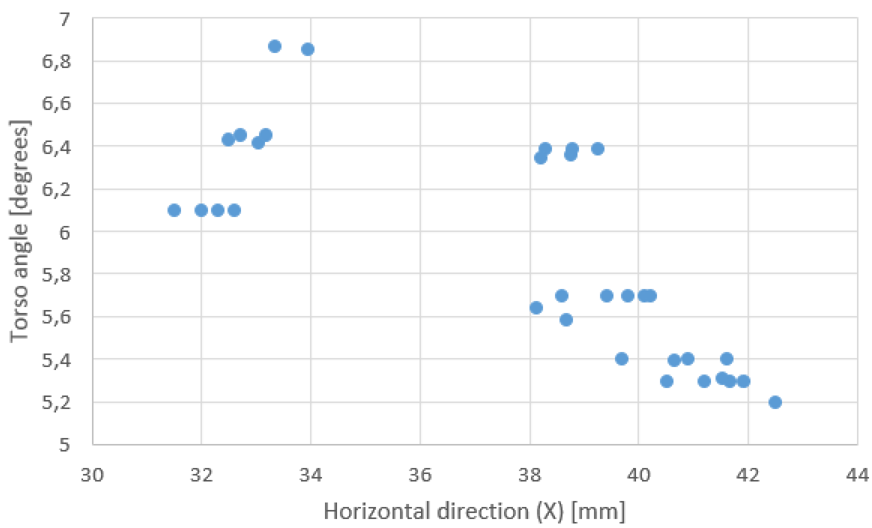

Figure 5.5: The relation between X and Torso angle for the Full Factorial Design.

The plot, in Figure 5.5, shows clearly a relation between X and Torso angle. Once again, it is wisely to remember that a lower X means that the manikin is positioned further forward in the seat.

The result shows that the manikin has a tendency of moving forward in the seat when the Torso angle increases, and vice versa. It is once again not a linear relation between them, saying that a small increase in Torso angle necessarily increases the X-coordinate. Instead, the global relation can be seen.

Similar to the previous relation study between Z and X, the result divides itself into two groups and the left group is clearly having a higher Torso angle average and is positioned more forward in the seat. The right group is instead having a lower Torso angle average and a higher X-coordinate average, being positioned further back in the seat.

5.1.2.3 Z vs Torso Angle

The Z-coordinates were compared to the Torso angles from the results of the Full Factorial Design. By comparing them against each other, Figure 5.6 could be displayed.

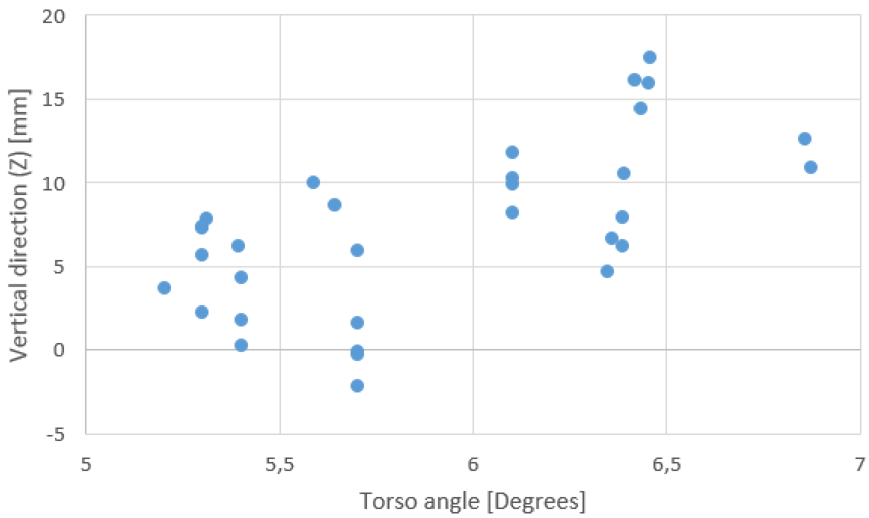

Figure 5.6: The relation between Z and Torso angle for the Full Factorial Design.

The plot, in Figure 5.6, shows clearly a relation between the Z-coordinates and the Torso angles. The pattern shows that the H-point, in Z-direction, increase together with a increased Torso angle. However, it does not apply for the individual case, being linearly increasing in Z-direction because of a small increase in Torso angle. Instead, it can be seen once again that the Z-coordinate increases with the Torso angle, on a more global level.

5.1.3 Analysis of Parameter Levels

The comparisons between X-coordinates, Z-coordinates and Torso angles, showed that relations existed between all the three of them. By knowing about their relations, the alternatives of the affecting parameters of the H-point could be analyzed in further detail, to find out what alternatives are increasing and decreasing the H-point.

The results in section 5.1.1, showed what parameters that affected the H-point the most, in Z-direction, X-direction and Torso angle. However, to analyze the alternatives of the affecting parameters and find out what alternative that resulted in a higher respective lower H-point, the factor effects plots and interaction plots were investigated, see Figure 5.7. The parameters affecting the most are shown in Table 5.4.

Table 5.4: The parameters affecting the most in Z, X and Torso angle.

Z-coordinate	X-coordinate	Torso angle
C - Upholstery	C - Upholstery	E - Manikin
E - Manikin	A- Leg extension	A - Leg extension
AC - Leg ext. & Upholstery	AC - Leg ext. & Upholstery	C - Upholstery
B - Foam hardness area 3	E - Manikin	
A - Leg extension	AE - Leg ext. & Manikin	
D - Foam density area 4	ACE - Leg ext., Upholstery & Manikin	

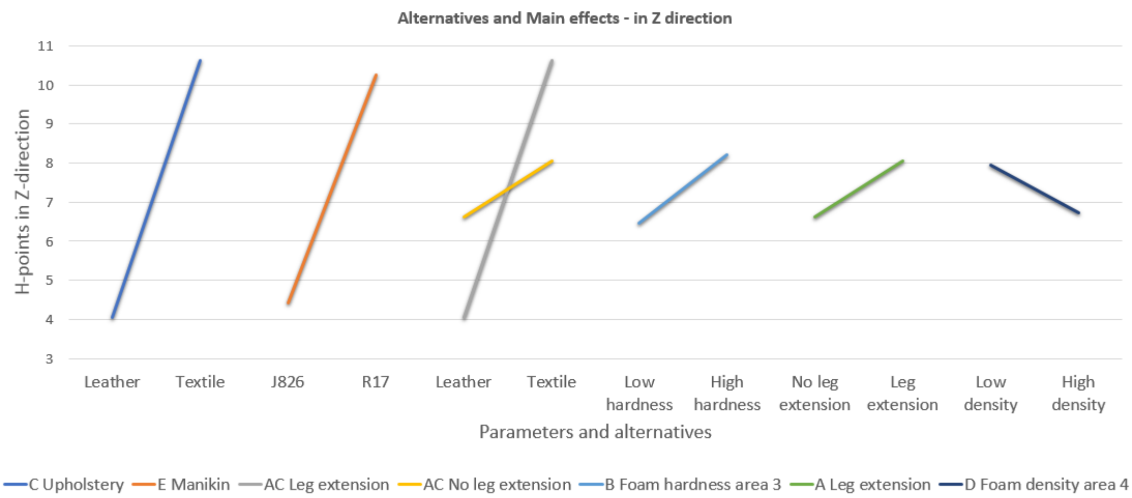

Figure 5.7: The factor effect plots, for the Z-direction.

The plot, in Figure 5.7, show the main effects of the parameters affecting the H-point in Z-direction. The higher slope, the more affecting the H-point. The slope is increasing or decreasing depending on if it is alternative -1 or 1 that is increasing the H-point in Z-direction.

Since the focus in the thesis have been primarily on the Z-coordinate and its direction, those are the parameters that have been analyzed in this section. However, since many parameters are in common for the Z-coordinate, X-coordinate and Torso angle, the most important factors of the X-coordinate and the Torso angle have been analyzed as well. The plots and the results of the Full Factorial Design showed that:

Upholstery. This parameter was affecting the H-point the most out of the investigated parameters in the Full Factorial Design, for the Z-direction and X-direction, and it was one of the parameters affecting the Torso angle the most.

The Upholstery had the alternatives of a textile type and a leather type. The plot, in Figure 5.7, showed that the H-point increased in Z-direction together with the textile type and decreased together with the leather type. It also showed that the textile made the manikin get a lower X, which means that it has a tendency to move forward in the seat, while the leather positioned the manikin further back in the seat.

The reason for why the textile would increase the H-point in Z-direction is probably that the textile material is more stiff than the leather material, which makes the H-point higher positioned in Z-direction. Another reason could be that the textile type has a two millimeter thicker foam padding than leather. Another reason could be that the textile had a tendency to increase the Torso angle. Because of the relations between the Torso angle, X and Z, an increased Torso angle would have affected the X-coordinate of moving forward in the seat, and a higher H-point in Z-direction.

To summarize the Upholstery and its alternatives, the textile alternative increased the H-point in Z-direction, moved the manikin forward in X-direction and increased the Torso angle, in comparison to the leather alternative.

Manikin. This parameter was the second most affecting parameter in the Full Factorial Design, in Z-direction. It was also one of the parameters affecting the most in X-direction and Torso angle. The Manikin had the alternatives of the 95 percentile person (J826) and the 50 percentile person (R17).

The plot, in Figure 5.7, shows that the H-point increased in Z-direction together with the R17 manikin and decreased with the J826 manikin. The reason for this can be explained by the leg length of the manikins, since that is what differs them. The R17 manikin clearly has shorter legs than J826, which is visible in the models as well.

The J826 gets a higher Z-coordinate of the knees, and thereby a more sloping thigh line, which ends up in a lower H-point. The R17 manikin, instead gets a lower Z-coordinate of the knees, and thereby a more horizontal thigh line, which ends up in a higher H-point. This can also be seen since the lower thighs of the R17 gets more contact with the leg extension part, while the J826 gets a gap between the thighs and the leg extension part, see Figure 5.8. In other words, the sloping thighs of J826 results in a lower H-point, than for R17.

Figure 5.8: The J826 (left) and R17 (right) and their contacts with the seat base.

For the Torso angle, the manikin had the highest influence of the parameters. It could be seen that for R17 manikin, the Torso angle increased, which in turn could have affected that it provided a higher H-point in Z-direction, based on the relation between Z and Torso angle. The manikin did not affect as much for the X-coordinate, as Z and Torso angle, but it was still one of the parameters affecting the X-coordinate the most, also showing that the R17 manikin had a tendency to move forward in the seat.

To summarize the Manikin and its alternatives, the R17 alternative increased the H-point in Z-direction, moved the manikin forward in X-direction and increased the Torso angle, in comparison to the J826 alternative.

Leg extension-Upholstery. This variable was the interaction between the leg extension and upholstery and it was the third most affecting variable in the Full Factorial Design, in Z-direction. It was also the third most affecting variable for the X-direction, but it did not seem to affect the Torso angle to the same extent. The plot, in Figure 5.7, shows that the H-points get higher Z-coordinates in the combination: Textile+Leg extension than Textile+No leg extension, and higher Z-coordinates in the combination: Leather+No leg extension than Leather+Leg extension.

The reason for this could depend on that the Textile+Leg extension variant is making the manikin slide forward in X-direction, which could affect the Z-coordinates, based on the found relation between Z and X. The interaction between the parameter of leg extension and upholstery could be confirmed by the plot, in Figure 5.7, where the lines are clearly intersecting each other.

To summarize the Leg extension + Upholstery and its alternatives, the alternatives with textile increased the H-point in Z-direction, no matter what leg extension alternative it was combined with. Textile combined with the leg extension alternative resulted in the highest H-points in Z-direction. The same combination also moved the manikin the most forward in X-direction. This parameter did not influence the

Torso angle to the same extent.

Foam hardness in cushion, area 3. This parameter was the fourth most affecting one in the Full Factorial Design, in Z-direction. However, it was not affecting the X-direction or Torso angle to the same extent. The alternatives it had were a high and a low hardness, within the middle area of the cushion. The plot, in Figure 5.7, shows that the H-point is getting higher positioned with a harder foam, and lower for a softer foam. This seems reasonable, since a harder foam should, according to theory, deform less in Z-direction and result in a higher H-point.

To summarize the Foam hardness and its alternatives, the high hardness alternative increased the H-point in Z-direction, in comparison to the low hardness. It did not affect the X-direction and Torso angle to the same extent.

Leg extension. This parameter was the fifth most affecting one in the Full Factorial Design, in Z-direction. It was also one of the parameters affecting the most in X-direction and Torso angle. The alternatives were to have a leg extension or no leg extension.

The plot, in Figure 5.7, shows that the leg extension resulted in a higher H-point than the combinations with no leg extension. The reason for this is probably because the part is originally higher when there is no leg extension part than with the leg extension part. This would cause a higher position of the manikin's thighs for the seats with no leg extension, and thereby cause a lower H-point in Z-direction. This means that when the seat includes leg extension, the thighs get a lower position and the manikin gets a more horizontal position. The horizontal position tended to provide the manikin with a forward movement in X-direction, which also could have impacted the Z-coordinate. The combination with leg extension did also result in a higher Torso angle, than the combinations with no leg extension.

However, the fact that the seats with leg extension seemed to result in higher H-points for the combination with J826, where the manikin does not have contact with the leg extension part, could be misleading and depend on the differences between the CAE models of the seats with leg extension and no leg extension, due to their earlier mentioned meshes.

To summarize the Leg extension and its alternatives, the leg extension alternative increased the H-point in Z-direction, moved the manikin forward in X-direction and increased the Torso angle, in comparison to the no leg extension alternative.

Density in cushion bolsters, area 4. This was the sixth most affecting one in the Full Factorial Design, in Z-direction. However, it was not affecting the X-direction or Torso angle to the same extent. The alternatives it had were high and low density, within the area of bolsters in the seat base.

The plot, in Figure 5.7, shows that a lower density would result in a higher H-point and that a higher density would result in a lower H-point. This does not seem reasonable, with respect to the theory behind density, since a higher density should have made the foam more rigid and thereby minimize the effect of the deformation of the foam, and result in a higher H-point.

However, it was discovered that the bolsters were deforming differently depending on the density. For a lower density, the bolsters got deformed by the manikin in Z-direction, like it should. For the higher density the bolsters were more rigid and kept its form. However, it was discovered that the bolsters with high density seemed to turn inwards when the manikin was positioned, which allowed the manikin to deform the inner cushion (area 3) and get an even lower H-point than for the low density.

This hypothesis can be seen in Figure 5.9, where the blue part represents the high hardness and the red part represents the low hardness, and the gray where they are overlapping each other. In the figure, one can see that the blue part is slightly turned inwards than the gray part. In the seat, it can also be seen that this results in a higher position of the red part in comparison to the gray part, which results in a higher H-point for the low density alternative.

Figure 5.9: The deformations of the bolsters with high (blue) and low (red) density.

To summarize the Foam density and its alternatives, the low density alternative increased the H-point in Z-direction, in comparison to the high density alternative. It did not affect the X-direction and Torso angle to the same extent.

5.2 Result of Validity Analysis

The results showed H-points between -3,8 and +25,9 mm, in Z-direction, which can be seen in Table F.2, in Appendix F.

5.2.1 Comparison Between Comfort and Sport Seat

The result showed that the parameters affecting the H-point in the Z-direction, for the four groups, were not falling into the same order. However, some similarities and differences between the Comfort seat simulations could be seen and likewise for the Sport seat simulations. Similarities and differences could also be seen between the two groups with the large difference in hardness and the two groups with smaller difference in hardness. See Table 5.5.

Table 5.5: The main effects from the four groups, in Z-direction.

	Comfort Large	Comfort Small	Sport Large	Sport Small
A Foam hardness area 1	-0,1523	0,0594	1,2825	1,7255
B Foam hardness area 2	0,7372	-0,4994	0,9740	0,1773
C Foam hardness area 3	2,4152	1,8799	2,7745	0,3880
D Foam hardness area 4	1,2348	0,1201	2,2255	5,1120
E Foam hardness area 5	0,3128	-0,5006	0,9260	0,2227
F Upholstery	9,1022	9,6406	4,1175	5,6745
G Manikin	4,3880	6,5276	1,0889	3,9908

To analyze the results and compare the four groups with each other, they were divided into four different analyzes. The first analysis was for the Comfort seat, comparing between the large and small difference in hardness. The second analysis was for the Sport seat, comparing the large and small difference in hardness.

The third analysis was for the large difference in hardness, comparing the Comfort and the Sport seat. The fourth analysis was for the small difference in hardness, comparing the Comfort and the Sport seat.

5.2.1.1 Comfort Seat: Large vs. Small Difference

The result, of Table 5.5, showed that the Comfort seat had similar affecting parameters, no matter if having the large or small difference alternatives in hardness. However, even though they showed the same affecting parameters, they appeared in different order, which could be appearing because of the choice of Orthogonal Array Design, which is having a lower accuracy than the Full Factorial Design.

The found similarities indicated that both the groups had the Upholstery, Manikin and Foam hardness area 3 as the most affecting parameters. They had also in common that the parameters Foam hardness area 1, area 2 and area 5 did not affect the Z-coordinate to the same extent.

A difference, that can be seen in Table 5.5, showed that the parameter of Foam hardness area 4 was affecting for the large difference in hardness, while it was not that affecting for the small difference in hardness. Since the main effect for Foam hardness area 4 still was around 1, it was believed to be confounded and not affect the H-point to the same extent as the other three affecting parameters. Additionally, earlier results of the Screening had shown that the Foam hardness of area 4 was not affecting to the same extent and the result of the Foam hardness area 4 was considered to be confounded and not correct.

In other words, the Foam hardness area 4 was not considered to be affecting the Comfort seat to the same extent as the Upholstery, Manikin and Foam hardness area 3.

5.2.1.2 Sport Seat: Large vs. Small Difference

The result, of Table 5.5, showed that the Sport seat had similar affecting parameters, no matter if having the large or small difference alternatives in hardness. However, similarly as the Comfort seat, the main effects of the parameters did not appear in the exact same order, even though they still showed that the same parameters affected the most. The similarities between the two groups for Sport seat was that the affecting parameters were Upholstery, Foam hardness area 4, Manikin and Foam hardness in area 1. They had also in common that the parameters Foam hardness area 2 and Foam hardness area 5 did not affect the Z-direction to the same extent.

A difference, that can be seen in Table 5.5, showed that the parameter of Foam hardness area 3 was affecting the large difference in hardness-group, but not the small difference in hardness-group. Since the main effect of the large difference in hardness-group was relatively high, 2,7745, the large difference is not considered as confounded results. The reason for why the small difference did not show the parameter as affecting, could be due to a threshold value in the Sport seat that needs to be breached before a significant change can be shown, or it could also be due to differences in the material cards used, or that it was simply confounded.

To summarize, the Sport seat was affecting in Z-direction by the Upholstery, Foam hardness area 4, Manikin, Foam hardness in area 1 and Foam hardness area 3.

5.2.1.3 Large Difference: Comfort vs. Sport

The result, of Table 5.5, showed that the large difference of hardness had some similarities for the Comfort and Sport seats. These were the affecting parameters of Upholstery, Manikin, Foam hardness area 3, and Foam hardness area 4. They had also in common that the parameters of Foam hardness area 2 and Foam hardness area 5 did not affect the H-point to the same extent.

A difference, that can be seen in Table 5.5, showed that the parameter of Foam hardness area 1 was affecting the Sport seat, but not the Comfort seat. A reason for this could be the fact that the Torso angle is higher for the Comfort seats, and the manikin has a tendency of moving forward in the seat for the Comfort seat in comparison to the Sport seat, which could explain why the middle part of the back does not have impact on the Comfort seat to the same extent as the Sport seat.

5.2.1.4 Small Difference: Comfort vs. Sport

The result, of Table 5.5, showed that the small difference of hardness had some similarities for the Comfort and Sport seats, but also some differences. The similarities were that they had the parameters of Upholstery and Manikin affecting the H-point. They had also in common that the parameters of Foam hardness area 2 and Foam hardness area 5 did not affect the H-point to the same extent.

A difference, that can be seen in Table 5.5, showed that the parameters of Foam hardness area 4 and Foam hardness area 1 affected the Sport and not the Comfort seat. It also showed that the Foam hardness area 3 affected the Comfort seat, but not the Sport seat, but since that was discussed earlier to be confounded, it was likely affecting the H-point. The difference of Foam hardness area 4 and Foam hardness area 1 were earlier found to be in common for the Sport seat groups, which indicated that those parameters affects the Sport seat to a larger extent than the Comfort seat.

5.2.1.5 Summary Between the Four Groups

The results showed that all the groups had in common to have the Upholstery, Manikin and Foam hardness area 3 affecting the H-point. This was considered to match the results of the Screening, where those three were the affecting ones out of those seven tested parameters.

It was also in common for the four groups that the Foam hardness area 2 (bolsters in back) and Foam hardness area 5 (leg extension part in the seat cushion) were not affecting the H-point in Z-direction to the same extent.

Besides those parameters in common, some differences showed that the Sport seat had more affecting parameters than the Comfort seat. The parameters of Foam hardness area 1 (middle part of the back) and Foam hardness area 4 (bolsters in seat cushion) did affect the H-point for the Sport seat, but not for the Comfort seat.

These differences indicated that the result of the Full Factorial Design, where the Comfort seat was investigated, cannot be applied directly on the Sport seat, since the parameters affecting the H-point seemed to be individual for each seat type.

5.2.2 Relations Between X, Z and Torso Angle

In the Full Factorial Design results, relations between the X-coordinate, Z-coordinate and Torso angle were found. To verify this result and investigate if the same relations could be established for both the Comfort seat and the Sport seat, an additional analysis was performed.

X vs Z

The X-coordinates were compared to the Z-coordinates from the results of the Validity Analysis. By comparing them against each other, Figure 5.10 could be displayed.

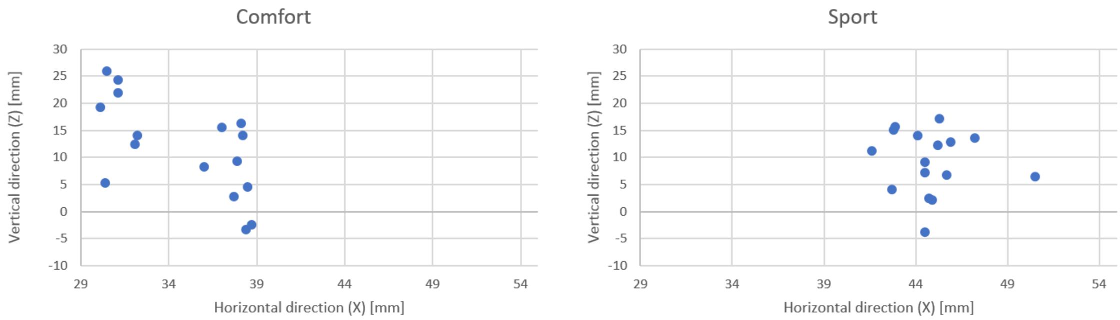

Figure 5.10: The relation between X and Z for the Validity Analysis.

The plot, in Figure 5.10, did show that the found relation from the Full Factorial Design could be confirmed for the Comfort seat, but not the Sport seat.

X vs Torso Angle

The X-coordinates were compared to the Torso angle from the results of the Validity Analysis. By comparing them against each other, Figure 5.11 could be displayed.

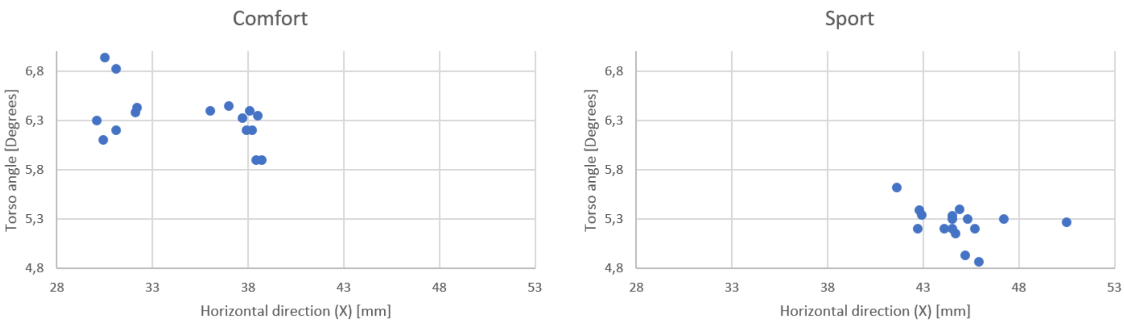

Figure 5.11: The relation between X and Torso angle for the Validity Analysis.

The plot, in Figure 5.11, shows that both the H-points for the Comfort seat and the Sport seat are increasing in the same direction, and confirms the found relation from the Full Factorial Design.

Z vs Torso Angle

The Z-coordinate were compared to the Torso angle from the results of the Validity Analysis. By comparing them against each other, Figure 5.12 could be displayed.

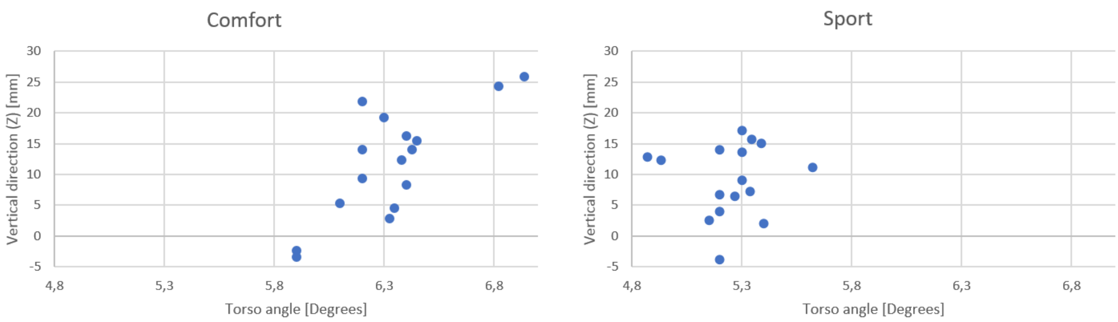

Figure 5.12: The relation between X and Torso angle for the Validity Analysis.

The plot, in Figure 5.12, shows that the relation from the Full Factorial Design could be confirmed for the Comfort seat, but not the Sport seat.

The conclusion from these results, are that the found relations between X vs. Z, X vs. Torso angle and Z vs. Torso angle, can be found and confirmed for the Comfort seat. However, the Sport seat can not confirm these relations to the same extent and need further investigations to be established.

5.2.3 Uncertainties in the Model Content

The CAE models that were used throughout the simulations, were all representations of the real and physical seats. However, some differences between the CAE models and the physical seats could be found, which decreased the accuracy of the representations. These mentioned differences are stated here, while the hypotheses for how the differences impacted the simulations, were further reflected on in the discussion.

5.2.3.1 Upholstery

The fact that the upholstery attachments did not exist in the CAE model, significantly reduced the reliability of the results. Another difference was that the Sport seat in the Validity Analysis was, in the CAE models, assigned with the same textiles and leathers as the Comfort seat used. In the reality, the Sport seat does not use neither of these upholsteries and should therefore, have been assigned with other types of upholsteries than the Comfort seat. However, the fact that these upholsteries did not exist within the CAE environment, probably affected the accuracy of the simulations.

5.2.3.2 Heating Mat

The modeling of the heating mat was an approximation. The physical heating mat consist of two sheets of non-woven fabric with a thin copper wire in between, to spread the heat. In the FE-model, this was modeled as a 3D solid element with no representation of the wire. This difference could have had impact on the results of the H-points.

5.2.3.3 Leg Extension

When comparing the seat with leg extension to the seat without leg extension, the models were, as mentioned earlier, from different stages of the development process and the model with leg extension, which was from a later stage, had a higher quality mesh. The results could therefore have been impacted by this difference, instead of the difference between leg extension and no leg extension, which was the one of interest.

5.3 Result of Foam Parameter Study

The result of the simulations in the Foam Parameter Study showed how the H-points vary, see Table G.2, in Appendix G.

The data used for comparison were physical measured H-points of seats with similar setups, but not identical. An average H-point for each upholstery was calculated from a number of different H-points with similar characteristics. However, the number of physical measured H-points were limited when comparing the different upholsteries, for example for one of the upholstery only a few H-points could be compared to, while for another upholstery many H-point results existed. The average for the three upholsteries can be seen in Table 5.6.

Table 5.6: The average H-points for the three upholsteries.

	X	Y	Z	Torso
Textile	42,5	-83,4	6,8	3,9°
Leather 1	44,7	-84,6	5,6	4,5°
Leather 2	42,7	-83,5	5,5	4,5°

The comparisons between the simulated H-points and the average of the physical measured H-points showed that the simulated H-points with textile became higher in Z-direction, in comparison to the average of the physical measured H-points. However, for the two leathers, the comparison showed the opposite.

For the leathers, the simulated H-points became lower in Z-direction, than the average of the physical measured H-points. In other words, the most suitable material combination for the textile would not be the most suitable material combination for the leathers. This can be seen in Figure 5.13. In the figure, it is also notable that all of the CAE H-points were having lower X-coordinates than the physical measured ones. The average H-point of textile is in green, and the average H-point of the leather is in orange.

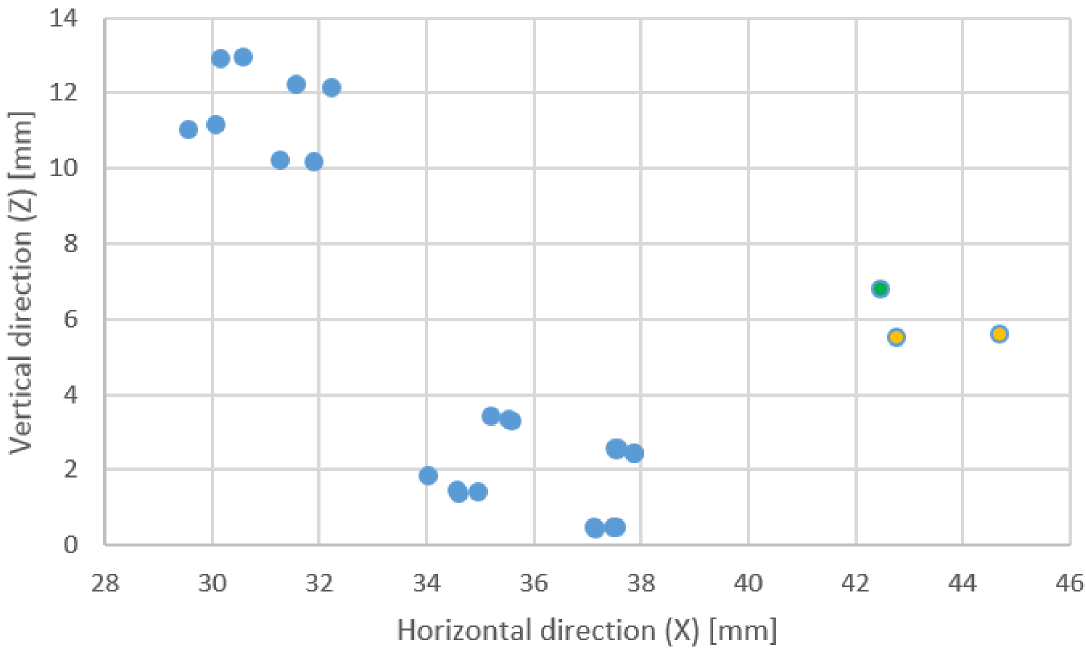

Figure 5.13: The comparison between CAE H-points and average of physical data.

To find a combination that would be equally suitable for the three upholstery types, it would be the combination of having foam type 2.1 in the back frame insert area and foam type 3 in the cushion insert area. The reason for why this combination was considered to be the most suitable one, was because the textile and the two leathers were having equally distances to their average, even though the textile still appeared over its average and the leathers under its average.

However, even though this study showed the most suitable material combinations with respect to foam hardness for the Comfort seat, it would need further investigation to be completely reliable.

5.4 Final Recommendations

The Final Recommendations in this section are the ones related to the parameters affecting the H-point. The recommendations regarding future work are stated in the discussion and conclusion.

- The result of the thesis shows that a specific formula for a general seat, that would explain how much each parameter affect the H-point, with the guarantee that it would work for all seats, could not be stated. The reason for this is that the result showed that different seat types would be having different parameters affecting the H-point. Even if the Comfort seat and Sport seat found common parameters affecting the H-point, there was no guarantee that it would be applicable for another platform than SPA. Besides, differences were also found between the Comfort seat and the Sport seat, where some parameters affected the H-point of the Sport seat but not the Comfort seat. All of these arguments spoke for the fact that different seats would have different parameters affecting the H-point.

Therefore, a recommendation is to perform an analysis of the parameters affecting the H-point, when a new seat variant is actual. To enable the possibility of experimenting with many parameters, but still limit the amount of simulations, and get reliable results, an Orthogonal Array Design of DOE is recommended. To enable the possibility of investigating the parameters in further detail, the recommendation is to screen down the parameters enough to perform a Full Factorial Design.

- The three parameters that the Comfort seat and Sport seat had in common of affecting the H-point were:

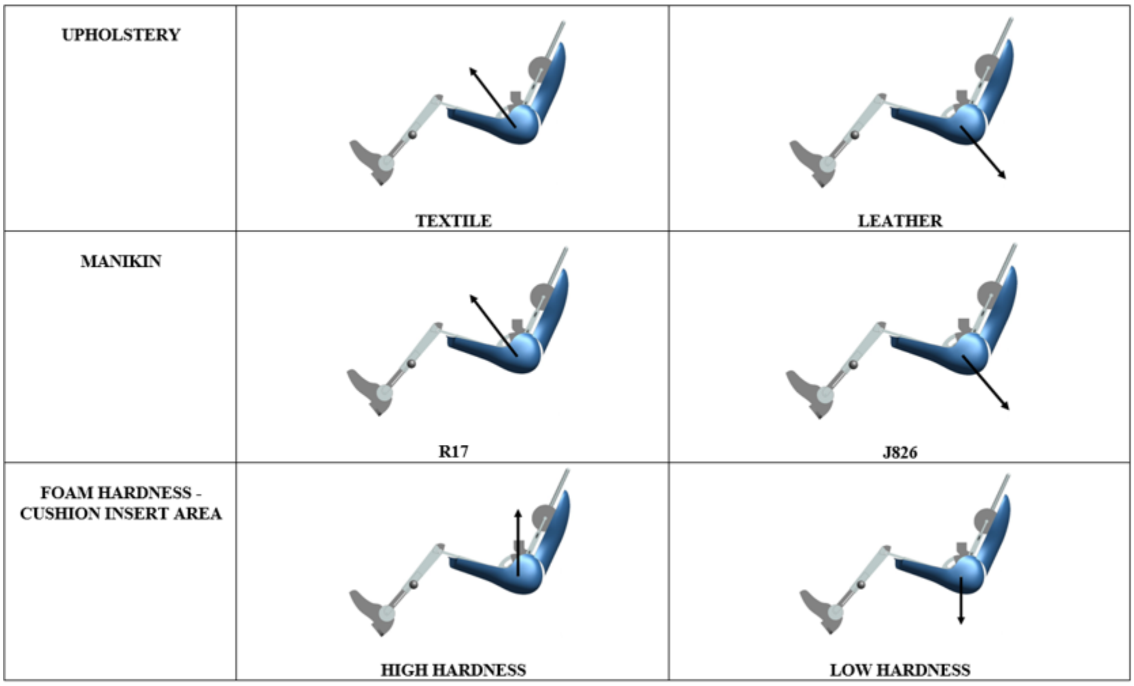

Figure 5.14: The guidelines regarding parameters to consider.

  - The Upholstery - the parameter that seemed to affect the Comfort and Sport seat the most overall, for Z-direction and X-direction. The textile resulted constantly in a higher H-point in Z-direction and a lower X-coordinate, moved forward in the seat, in comparison to the leather alternative. This parameter was therefore considered to be an important parameter, that is recommended to take into consideration when evaluating the H-point.

  - The Manikin - the second parameter that seemed to affect the Comfort and Sport seat the most, in Z-direction and X-direction. Logically, the

J826 (95 percentile manikin) should constantly result in a lower H-point in Z-direction than the R17 (50 percentile manikin), based on the findings in the thesis.

A recommendation is therefore to use the taller manikin, if a lower H-point is desired. However, it is important to keep in mind the fact that the subcontractor only performs physical tests on the R17 manikin, if results from them should be compared to. It is also important to ensure the regulations around what manikin is valid for what market, for example if it is valid to use the J826 manikin for the European market despite the fact that the regulation about R17 comes from Europe.

– The Foam hardness in the cushion insert area - the third parameter to affect the H-point of the Sport and Comfort seat. The high hardness resulted in a higher H-point, in Z-direction.

- Relations were found between the Z-coordinates, X-coordinates, and Torso angle, in both the Sensitivity Analysis and the Validity Analysis. The relations seemed to appear more clearly for the Comfort seat, than for the Sport seat. Therefore, it is recommended to take this into consideration for the Comfort seat, and to investigate it further for the Sport seat and other seat types.

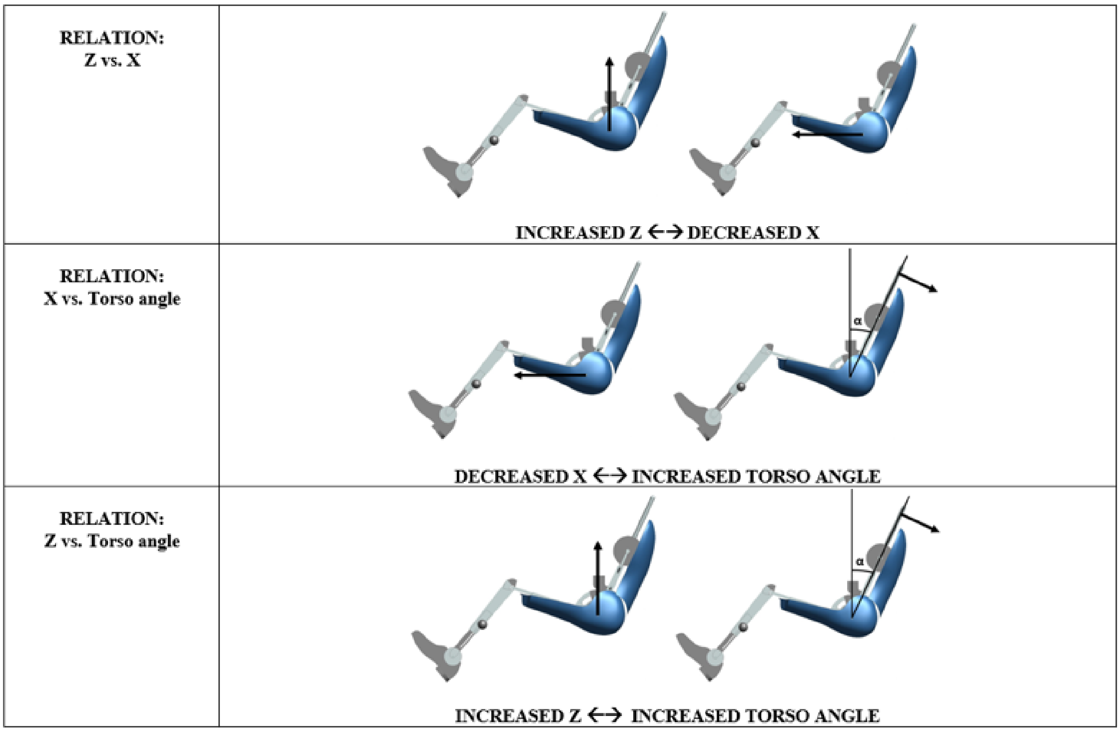

Figure 5.15: The guidelines regarding relations to consider for the Comfort seat.

- The Foam Parameter Study was limited to the Comfort seat of SPA as well, and it showed that the Foam hardness of the leg extension part was not affecting the H-point to the same extent as the other two insert areas.

The result showed that there would be different suitable material combinations with foam hardnesses based on the upholstery type. The recommendation ended up to be: A combination that is supposed to be suitable for all combinations and not impairing for the other upholstery type, the recommended combination is: 2.1 in the back frame insert area and 3 in the cushion insert area, since the combination of those two made the textile and leather seats differ equally much from the averages of physical H-points.

However, to ensure the results even further, more physical measured H-points would have been needed, to get more reliable averages to compare against.

5.5 Summary of Results

This chapter has showed and analyzed the result from the Full Factorial Design, the Validity Analysis and the Foam Parameter Study. The Full Factorial Design resulted in different parameters affecting in X-direction, Z-direction and Torso angle. Relations could also be found between these three, which were confirmed by the Validity Analysis result. The result of the Validity Analysis also indicated that the parameters affecting the Comfort seat variant would not necessarily be the same for the Sport seat.

The result of the Foam Parameter Study indicated that the suitable material combination of foam types was with foam type 2.1 in the back insert and foam type 3 in the cushion insert, to get as close to the physical measured H-points as possible. The result of these phases were then used as a base to create recommendations for the company to consider.

6
Discussion

This chapter discusses the answers to the research questions, implications with the research methodology and uncertainties with the results of the simulations, while consolidating the results with the process.

6.1 Answers to Research Questions

Are the same parameters affecting the H-point of all seat types, or is it individual?
The result of the thesis showed similarities between the Comfort seat and the Sport seat in parameters affecting the H-point. However, it was discovered that the Sport seat had more parameters affecting the H-point, that were not applicable for the Comfort seat. This result was interpreted to the conclusion that it is not possible to state a general formula for what parameters that affect the H-point, since it seems to be individual for each seat type.

What parameters influence the coordinates of the H-point?
For the Comfort seat, it was discovered that many parameters influenced the coordinates of the H-point, in different directions. The parameters found to be influencing the H-point in Z-coordinate were: Upholstery, Manikin, Foam hardness in the cushion insert part, Leg extension and Foam density in the bolsters of the seat base. The parameters found to be influencing the H-point in X-direction were: Upholstery, Leg extension, and Manikin.

However, the three parameters that affected the Z-direction for both the Comfort seat and Sport seat were: Upholstery, Manikin and Foam hardness in the cushion insert of the seat base.

How does these parameters interact and influence the H-point?
The results of the thesis showed that some parameters interacted with each other and influenced the H-point. In Z-direction, the interaction between the Leg extension and the Upholstery seemed to influence. In X-direction, the interaction between the Leg extension and Upholstery, the interaction between the Leg extension and Manikin, and the interaction between Leg extension, Upholstery and Manikin seemed to influence. How each parameter influenced the H-point individually in Z-direction through its alternatives, is stated in the analysis.

What guidelines for parameters can be established and with what accuracy?
The result showed that the Upholstery, Manikin and Foam hardness in the cushion insert area of the seat cushion, were affecting both the Comfort seat and the Sport seat.

The textile did increase the Z-coordinate and decrease the X-coordinate (moving forward in the seat), in comparison to the leather. The R17 manikin did also increase the Z-coordinate and decrease the X-coordinate, in comparison to the J826. A higher foam hardness in the cushion insert area resulted in a higher H-point in Z-direction.

Relations were also found between the Z-coordinate, X-coordinate and Torso angle, which seemed to appear more clearly for the Comfort seat, than the Sport seat. The relations were that the Z-coordinate increased with a decreased X-coordinate, that the X-coordinate decreased with a increased Torso angle, and that the Z-coordinate increased with a increased Torso angle.

The accuracy of these guidelines could unfortunately not be completely confirmed, since more investigations, more accuracy with the CAE models, and more physical results would be needed. However, the results are still considered as guidelines and hypotheses towards the future.

What materials are suitable to use together, to represent the hardness of the foam in the CAE method? Why?
For the Comfort seat, the recommended material combination is: Type 2.1 in the back frame insert area and 3 in the cushion insert area. The reason why these combinations were chosen, was because of their relations to the average of physical measured H-points. However, more investigation would be needed to ensure the best material combination for the Comfort seat and other seats.

6.2 CAE Models

The results from the Validity Analysis showed that some of the CAE models included differences in comparison to the representations of the physical seat. In this section, the implication of the differences are discussed.

6.2.1 Upholstery

If the upholstery attachments would have existed within the CAE models, then it could have had a significant impact on the simulations. The reason for believing this, is because when fastening the upholstery in the real seat, both the upholstery and the foam are in tension, which they are not in the CAE models. With this tension, the foam would probably not slip against the upholstery, due to the high friction force. This would also push the foam towards the center - forming a sort of hill in the middle. All of these reasons are creating a hypothesis, where it is believed that the H-points in the CAE simulations would increase in Z-direction, if the attachments existed in the CAE model. Since the H-points would probably not increase linearly with the existence of upholstery attachments, it would be of interest to investigate if other parameters would have affected the H-point with the existence of upholstery attachments.

If the correct upholstery would exist for the Sport seat, the H-points would probably have showed other results than for this thesis. The reason for believing this, is that the upholstery showed a large impact in general on the H-point. However, for the Sport seat there is only one upholstery type available, which would mean that if the upholstery would exist, there would not be any alternatives to compare to. The H-point would hypothetically become lower with the correct Sport upholstery, than in the simulations of this thesis, since the tension is believed to be higher for the textile and leather. To know for sure, how it would differ, it would be of interest to include the correct upholstery of the Sport seat and see if the upholstery still would affect the most.

Another thing about the upholstery that may had influence on the output was that the thickness of the upholstery was constant all the time in the CAE models, even though they should have varied. These could have had impact on the result, since the textile got a thicker upholstery than what it has in the reality. If the correct representation would have existed in the models, the difference in H-points between the textile and leather could have been smaller. However, even though the effects would have changed, the result of the upholstery affecting the H-point would probably remain.

6.2.2 Heating Mat

If the heating mat would have included the two sheets of non-woven fabric and thin copper wire in between, instead of being just a 3D solid element, it would probably have affected the H-points in the simulations. This since the fabric of the heating mat is stiff and is believed to elevate the H-point. However, it is unclear how much it would change the H-point.

6.2.3 Leg Extension

Since differences were found between the leg extension and no leg extension CAE models, regarding the mesh quality, these could have affected the H-point simulations to a large extent. A fact that strengthens the reasoning behind the previous statement was that in the simulations with the J826 manikin, the leg extension vs. the no leg extension had impact on the H-point, even though the manikin did not have contact with that part. This indicated that there was some definitive model differences between the high quality mesh and the low quality mesh use, and that it was the difference between those that impacted the H-point, and not the leg extension vs. no leg extension that was of interest. However, the result for the R17 seemed to be more accurate, since then it had actual contact with the part.

To summarize the discussion about the CAE models, the CAE model representation of the physical seat is believed to be the most critical aspect of influencing the accuracy of the simulations with H-point prediction. Before analyzing further simulations and starting to compare against more physical seats, this should be prioritized.

6.3 Simulations and Design of Experiments

In this section, the simulation process is reflected upon and how the design of the DOE impacted the output.

6.3.1 Screening

The output from the Screening had the risk of being confounded, since it was using the Orthogonal Array Design, which was the smallest Fractional Factorial Design that still could analyze the main effects of each factor. On one hand, the results of the Screening could have been seen as not accurate due to the risk of getting confounded main effects of the parameters. On the other hand, the Full Factorial Design showed that the same parameters that affected the H-point in the Screening, also affected the H-point in the Full Factorial Design, which indicated that the result would be accurate. This confirms that it was an appropriate method, to screen out the parameters that did not affect the H-point, and still keep the number of simulations low.

6.3.2 Full Factorial Design

The Full Factorial Design involved systematic exploration of every combination of each factor, which meant that the the Full Factorial Design had the highest accuracy of DOE's. However, the accuracy could still be influenced by the choice of parameters. For example, in the Screening, the gap between high and low setting of each parameter was in general higher than in the Full Factorial Design, as the Screening was made to exclude the parameters that had a significant impact while the focus of the Full Factorial Design was to provide more accurate information on how much the parameter in question influenced. Therefore, it is considered to be a higher accuracy in general for the Full Factorial Design, than the Screening.

6.3.3 Validity Analysis

The verification between the Comfort seat and the Sport seat was based on an Orthogonal Array Design and the results showed that it seemed to exist some confounded results there. Since the Screening did not indicate confounded results, it was considered as an appropriate method for the Validity Analysis, where the number of runs would be limited. However, since confounded results were found, the Validity Analysis was considered to be less accurate than expected. It was still believed to have some accuracy regarding the parameters with the largest impact on the H-point, since it indicated similarities between the Sport seat and the Comfort seat. However, the findings regarding others than the top and bottom parameters are harder to say something about, especially for the Sport seat, since it did not have any earlier simulations to compare to. To increase the level of accuracy for the Validity Analysis, it would have been interesting to make a Screening and a Full Factorial Design for the Sport seat, and then compare against the Comfort seat.

The desired approach, mentioned above, was not possible to perform due to the limitations of the thesis. In the beginning of the project the Comfort seat was the only seat available to perform CAE simulations on, while the Sport seat became available at the end of the thesis. Because of the time constraint, the Sport seat and the Comfort seat were compared only in the Validity Analysis. If both models would have existed in the beginning of the project, then two screenings using the Orthogonal Array Design and two Full Factorial Designs could be used to compare the two models between them. Unlike the method that was used, this would provide better accuracy regarding how much each of the parameters are influencing the system.

The output that came from the Validity Analysis was that not all the parameters affected the H-point in the same way. To eliminate the influence of confounding from the Orthogonal Array Design that was used to compare the Sport seat with the Comfort seat, it is suggested that a comparison of the results from a Full Factorial Design or a Fractional Factorial of the appropriate size is made instead. For example, if five parameters are identified of high influence of the H-point in the Comfort seat, and an additional two for the Sport seat, then a comparison of two Fractional Factorials with seven parameters each could be made to compare the influence without risks for confounding the results.

There is also a concern regarding the representation of the upholstery attachments. In the results from the Sport seat it showed that the hardness of the bolsters had a significant impact on the H-point. This could be due to the shape of the bolsters, that differ between the seat types, but it could also be because of the non-existent upholstery attachments in the CAE model. In that case, the foam deforms freely, while under the influence of the attachments they would deform with certain restraints. To verify this hypothesis, an idea would be to perform physical measurements of the H-point on a seat without using the upholstery attachments and instead glue the upholstery to the foam.

One way to increase the reliability in the simulation results overall, would be to conduct more physical tests with the DOE setup that was used during the Screening and Full Factorial Design, in this thesis. If these would show the same output as the simulations, then that would ensure reliability in the simulation results. However, this would be a very costly solution for verification.

6.4 Foam Parameter Study with Physical Data

The physical measured H-points that existed on data that were available for verification, was not extensive enough to provide reliability in the simulation results in the Foam Parameter Study. An implication with the dataset, was that there was an overwhelming amount of one particular seat setup, with one particular upholstery, which resulted in that the other seats with other upholstery types, got a less real representation. The average for the seats with less real representation in the dataset, could therefore not be considered to have as great confidence in the average as the seat that had more results to compare against.

To make a more accurate Foam Parameter Study of suitable materials to use within CAE, more data of physical measured H-points for different seats would be needed and a more thorough analysis of the materials would be suggested.

6.5 Ready or Not for Implementation?

One interesting scenario to discuss is if/when the accuracy of the results, of the parameters affecting the H-point of different type of seats, would have been a hundred percent confirmed. What would the next step be then? Would it be to implement the CAE prediction method of H-points to the product development process? With the data that we have had available during this thesis, we would suggest further investigations to establish further understanding of the relationship between the CAE predicted H-points and the physically measured H-points.

- First, it would be of interest to confirm the parameters affecting the H-point on the physical seats, to ensure that the physical seats are having the same parameters affecting the H-point as the CAE models. Even if the CAE models are supposed to be representing the physical seats, it needs to be confirmed properly.

- Another step would be to establish the relation between the CAE H-points and the physical measured ones for different seats. For example, even though there will probably always be a difference between the H-point of a physical seat and the H-point of a CAE modeled seat, a pattern of the relation should be able to be stated, saying that the CAE H-point is always 5-10 mm under the physical H-point or vice versa. This needs to be known, before implementing the method to the product development process.

Once these investigations are performed, we think that the company is ready for implementing the method to the product development process, and start to predict the H-point through CAE.

6.6 Recommendations for Future Research

The CAE models, that have been available during this thesis, did not fully represent the physical seats. The department is, however, currently updating the CAE models of the seats with more accurate representations of the physical seats. A recommendation is to investigate these further, to evaluate the accuracy of the new CAE modeled representations. One of the updates includes a representation of the upholstery attachments, which is believed to be of utmost importance, since the attachments will affect how the foam will deform, which in turn will affect the H-point.

In order to increase the reliability in the Validity Analysis, a more thorough comparison of the Comfort seat versus the Sport seat needs to be performed, as the results of the simulations with design of experiments for this thesis were a bit confounded. A suggestion would be to perform another Screening for the Sport seat as well and there identify which parameters are influencing the H-point the most and then combine these parameters with the parameters that affected the Comfort seat the most. With these parameters it would then be recommended to perform a type of Fractional Factorial Design. Even though the best option would be to perform a Full Factorial Design, this however, comes with a high cost of simulation times and model preparations. A Fractional Factorial Design with the same parameters would, however, be suggested as it provides good results still but the number of runs required are reduced to a fraction of the Full Factorial Design. An Orthogonal Array Design should only be used for a possible screening, since confounded results can be found otherwise.

Another recommendation would be to do the same type of analysis, but with another type of seat than the Sport seat, to see which parameters that could be applied to other seats as well. It could also be of interest to do the same type of analysis for other cars than the XC90.

Another recommendation would also be to continue the Foam Parameter Study by interpolating the existing material cards to create new ones that would represent another foam with slightly increased or slightly decreased hardness in order to find materials that represent the physical seats well.

Something that also could be explored further, is the effect that the shape of foam has on the H-point coordinates. As could be seen in the Screening, the shape of foam had a significant impact on the H-point. So by performing further experiments and varying parameters such as insert width, bolster height and bolster radius, data of high interest can be provided.

Before implementing the prediction of H-points through CAE to the product development process, the recommendations are to first establish the desired accuracy of the parameters affecting each seat type, then to confirm the parameters affecting the H-points of the physical seats to be the same as in CAE. Then the recommendation is to establish the relation between CAE H-points and the physical measured ones.

7
Conclusions and Future Research

This chapter concludes the thesis and states the recommendations for future research.

7.1 Conclusions

The project was performed to increase the knowledge, within the Department of Seats at Volvo Car Corporation, of parameters affecting the H-point in CAE. The purpose of the thesis was to investigate in what parameters that affects the H-point and if the same parameters are affecting the H-point of all seat types, or is it individual for the seat type.

The findings of the thesis showed that two seat types, Sport and Comfort for the SPA platform, seemed to have in common three parameters that affected the H-point, in Z-direction. These were the Upholstery, the Manikin and the Foam hardness in the seat base. However, despite the findings of the common parameters, further parameters affected the H-point of the Sport seat and not the Comfort seat. This result indicates that the parameters affecting the H-point is individual for each seat type, and that it cannot be applied directly from one seat type to another. Relations were found, between the Z-coordinate, X-coordinate, and Torso angle, that seemed to be applicable on the Comfort seat, but not the Sport seat.

The accuracy of the findings is not completely reliable and therefore, further investigations are needed to increase the reliability. However, the findings are still of value and are considered as guidelines and hypotheses for the future.

7.2 Future Research

It is recommended that the company take advantage of the work that is performed within this thesis and continues the research. For future research, it is recommended to:

- Continue to update the CAE models with more accurate representations of the physical seats. They are then recommended to be further investigated, through simulations, to evaluate the accuracy of the new representations.

- Increase the reliability in the Validity Analysis, by performing further investigations regarding the Sport seat. It is also recommended to compare against more seats than just the Sport seat, and other cars than the XC90.

- To continue the Foam parameter study and interpolate the existing material cards, to investigate the hardness representation more.

- To investigate further in the shape of foam parameter, since that had significant impact on the H-point.

In general, before implementing the method of predicting the H-point through CAE to the product development process, the recommendations are to:

1. First establish the desired accuracy of the parameters affecting the seat type to a desired level, since the findings in this thesis are considered to be guidelines/hypotheses and the desired level of accuracy needs to be further defined.

2. Then confirm the parameters affecting the H-points of the physical seats to the same as in CAE. Other patterns found in CAE should also be confirmed.

3. Finally, to establish the relation between CAE H-points and the physical measured H-points, so that the company know for sure where the physical H-point will end up, in relation to the predicted H-point.

Once these actions have been performed, the company is considered to be ready for implementing the method to the product development process, and start to predict the H-point in CAE.

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A

Appendix: H-points from the Observation

Here are the H-points from the observation in the Problem Exploration phase. Note that only the H-points from the XC90 platform are stated here. The three seats are identical, with only manufacturing variances differing.

Table A.1: The physically measured H-points from the observation.

Seat	Manikin	X	Y	Z	Torso angle
1	J826	41,3	-84,5	4,8	25,0
2	J826	38,3	-84,2	4,5	24,8
3	J826	41,0	-82,2	6,2	25,3
1	R17	41,7	-83,5	6,3	25,3
2	R17	41,1	-83,2	6,8	25,2
3	R17	39,5	-83,9	6,7	25,3

B

Appendix: Screening Setup and H-points

The Screening Orthogonal Array Design is presented here, together with the H-points that the Screening resulted in.

The 16 runs in Table B.1 shows the combinations of 16 seats, with the alternatives from Table 4.2.

Table B.1: 16-run Orthogonal Array Design for Screening.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	*y1*
2	1	1	1	1	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	*y2*
3	1	1	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	*y3*
4	1	1	1	-1	-1	-1	-1	-1	-1	-1	-1	1	1	1	1	*y4*
5	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	*y5*
6	1	-1	-1	1	1	-1	-1	-1	-1	1	1	-1	-1	1	1	*y6*
7	1	-1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	1	*y7*
8	1	-1	-1	-1	-1	1	1	-1	-1	1	1	1	1	-1	-1	*y8*
9	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	1	-1	*y9*
10	-1	1	-1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	*y10*
11	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	*y11*
12	-1	1	-1	-1	1	-1	1	-1	1	-1	1	1	-1	1	-1	*y12*
13	-1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	*y13*
14	-1	-1	1	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	*y14*
15	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	1	-1	*y15*
16	-1	-1	1	-1	1	1	-1	-1	1	1	-1	1	-1	-1	1	*y16*

Table B.2: H-points - Result of Screening.

	X	Y	Z
1	28,4	-85,2	25,2
2	35,7	-85,0	19,4
3	27,6	-85,1	24,6
4	34,0	-85,0	20,9
5	34,9	-85,0	18,7
6	33,6	-85,0	17,3
7	28,5	-85,2	20,7
8	35,0	-85,1	15,8
9	33,1	-85,2	15,4
10	23,1	-85,0	27,4
11	36,8	-85,3	8,7
12	31,5	-85,1	22,7
13	39,3	-85,3	13,2
14	31,0	-85,0	27,7
15	38,0	-85,9	20,7
16	25,0	-85	29,5

Due to confidential information, the results of the H-points are described from a nominal value of 0, which differ from the actual coordinates that the simulations gave.

C

Appendix: Checklist for Stability of the Simulations

This checklist was used for all the simulations during the project, to make sure the result would be reliable to trust.

- **Check the interface between the manikin and the seat**. Since the seat model was created first and the manikin was then positioned to the seat model, parts could clash in the model, e.g. the manikin falls right through the foam. This were considered as unrealistic in comparison to what could happen in the reality, and was therefore included in the checklist to make sure it did not happen.

- **Check the stability of the curve**. In order to make sure that the coordinates were stabilized and thereby could be trusted, this was checked in the softwares Meta or Animator. It was done by comparing the coordinates of the H-point with the time the simulation ran. See Figure C.1, where the Z-displacement can be seen on the Y-axis and the simulation time can be seen on the X-axis.

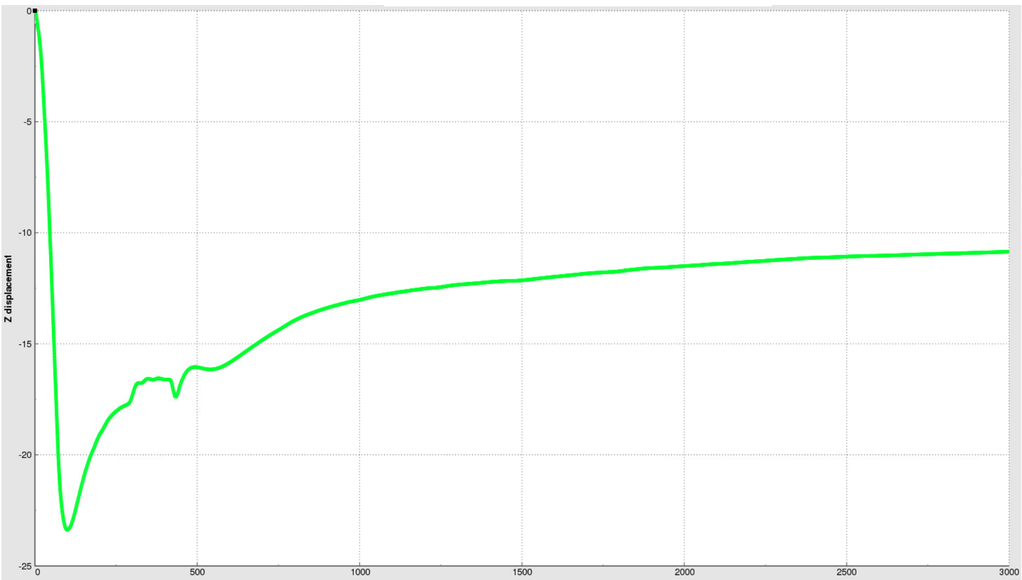

Figure C.1: The curve of the displacement in Z-direction, through one simulation.

- **Check the difference between left and right H-point**. To make sure the manikin would not be sitting too skewed, a comparison was made for the left and right H-point in X-direction and Z-direction. Here it was decided to not approve a larger difference than 2 millimeters, since that would complicate the analyze of the results.

D

Appendix: Matlab Code for Analyzing DOE Results

The Matlab code that was used for the Screening is displayed in this Appendix. Since the Matlab code for the Full Factorial Design and Validity Analysis were based on this code, this code got to represent the Matlab code used within this project.

```
clear variables
close all



Z = loaddata;
% Loads Z values from loaddata.m
% script runs for 8 or 16 inputs
%

DOE = loaddoe(Z);
% Loads DOE from loaddoe.m
% Works for 8 or 16 runs

sv = size(DOE);
% sv is a vector containing numbers of rows and numbers
   of coulmns of DOE

contrast=contrastfunction(sv,DOE,Z);
% contrastfunction calculates the contrast of each
   parameter

main=contrast/(sv(1)/2);
% the main effect is calculated by dividing the contrast
   by half the number of runs


ss=sumofsquares(sv, contrast);
% sumofsquares calculates the sum of squares for each
   contrast
```

```
mains=sort(main);
% mains is a sorted vector of main, going from low to
   high

y = zeros(sv(2),1);
for i = 1: sv(2)
    y(i,1) = (i/(sv(2)+1));
end
% Divides into percentages

for i = 1:15
    mainss(i,1)=main(i);
    mainss(i,2)=i;
    ss(i,2)=i;
end

mainsss=sortrows(mainss,1)
sss=sortrows(ss,1)


plotfunction(sv,mains,y);
%plots the normal probability plot for the given values

%%%
% loaddata.m
function Z = loaddata

Z = [25.2
    26.6
    24.6
    21.1
    19.5
    17.5
    20.7
    22.8
    15.4
    27.6
    09.1
    23.3
    13.5
    28.2
    20.7
    30.5];

end
```

```
%%%
%%%
% loaddata.m
function DOE = loaddoe(Z)


if length(Z) ==8
    DOE = [1  1  1  1  1  1  1
        1  1  1  -1  -1  -1  -1
        1  -1  -1  1  1  -1  -1
        1  -1  -1  -1  -1  1  1
        -1  1  -1  1  -1  1  -1
        -1  1  -1  -1  1  -1  1
        -1  -1  1  1  -1  -1  1
        -1  -1  1  -1  1  1  -1];
elseif length(Z) == 16
    DOE = [ +1   +1       +1       +1       +1       +1
       +1       +1       +1       +1       +1       +1       +1
             +1       +1
            +1   +1       +1       +1       +1       +1
               +1       -1       -1       -1       -1       -1
                     -1       -1       -1
            +1   +1       +1       -1       -1       -1
               -1       +1       +1       +1       +1       -1
                     -1       -1       -1
            +1   +1       +1       -1       -1       -1
               -1       -1       -1       -1       -1       +1
                     +1       +1       +1
            +1   -1       -1       +1       +1       -1
               -1       +1       +1       -1       -1       +1
                     +1       -1       -1
            +1   -1       -1       +1       +1       -1
               -1       -1       -1       +1       +1       -1
                     -1       +1       +1
            +1   -1       -1       -1       -1       +1
               +1       +1       +1       -1       -1       -1
                     -1       +1       +1
            +1   -1       -1       -1       -1       +1
               +1       -1       -1       +1       +1       +1
                     +1       -1       -1
            -1   +1       -1       +1       -1       +1
               -1       +1       -1       +1       -1       +1
                     -1       +1       -1
            -1   +1       -1       +1       -1       +1
               -1       -1       +1       -1       +1       -1
                     +1       -1       +1
```

```
            -1   +1         -1         -1         +1         -1
               +1         +1         -1         +1         -1         -1
                     +1         -1         +1
            -1   +1         -1         -1         +1         -1
               +1         -1         +1         -1         +1         +1
                     -1         +1         -1
            -1   -1         +1         +1         -1         -1
               +1         +1         -1         -1         +1         +1
                     -1         -1         +1
            -1   -1         +1         +1         -1         -1
               +1         -1         +1         +1         -1         -1
                     +1         +1         -1
            -1   -1         +1         -1         +1         +1
               -1         +1         -1         -1         +1         -1
                     +1         +1         -1
            -1   -1         +1         -1         +1         +1
               -1         -1         +1         +1         -1         +1
                     -1         -1         +1];
else
    disp('Error Z values not 8 or 16')
    DOE = [];

end
end

%%
%%
% contrastfunction.m
function contrast = contrastfunction (sv,DOE,Z)

contrast=zeros(sv(1,2),1);
for k= 1:sv(1,2)                                          % where k
    is contrast row
        for i= 1:sv(1,1)                                  % where i
            is the vector row
            contrast(k,1)= contrast(k,1)+DOE(i,k)*Z(i,1);
        end
end
end
%%
%%
% sumofsquares.m
function ss = sumofsquares(sv, contrast)

ss=zeros(sv(1,2),1);
for i = 1:sv(1,2)
```

```
    ss(i,1)=(contrast(i,1)^2)/(2*2^3);
end
end

%%%
%%%
% plotfunction.m
function plotfunction(sv,mains,y)

hold on;

if mains(1)>= 0
    min=mains(1)+0.5;
else
    min=mains(1)-0.5;
end

if sv(1) == 8
    linje=@(x)(0.5/(mains(6)-mains(2)))*x+0.5;
    if mains(sv(2))>= 0
        max=mains(sv(2))+0.5;
    else
        max=mains(sv(2))-0.5;
    end
elseif sv(1) == 16
    linje=@(x)(0.5/(mains(12)-mains(4)))*x+0.5;
    if mains(sv(2))>= 0
        max=mains(sv(2))+0.5;
    else
        max=mains(sv(2))-0.5;
    end
end


fplot(linje,[min max])
plot(mains,y,'*')
%legend('x','y');
title('Normal Probability Plot');
xlabel('Main-effect');
ylabel('Percentile');
axis([min max 0 1])
set(findall(gca, 'Type', 'Line'),'LineWidth',3);
hold off
end
%%%
```

E

Appendix: Full Factorial Design Setup and H-points

The Full Factorial Design Setup is presented here, together with the resulted H-points.

Table E.1: 32-run Full Factorial Design matrix.

	A	B	C	D	E	
1	-1	-1	-1	-1	-1	*y1*
2	1	-1	-1	-1	-1	*y2*
3	-1	1	-1	-1	-1	*y3*
4	1	1	-1	-1	-1	*y4*
5	-1	-1	1	-1	-1	*y5*
6	1	-1	1	-1	-1	*y6*
7	-1	1	1	-1	-1	*y7*
8	1	1	1	-1	-1	*y8*
9	-1	-1	-1	1	-1	*y9*
10	1	-1	-1	1	-1	*y10*
11	-1	1	-1	1	-1	*y11*
12	1	1	-1	1	-1	*y12*
13	-1	-1	1	1	-1	*y13*
14	1	-1	1	1	-1	*y14*
15	-1	1	1	1	-1	*y15*
16	1	1	1	1	1	*y16*
17	-1	-1	-1	-1	1	*y17*
18	1	-1	-1	-1	1	*y18*
19	-1	1	-1	-1	1	*y19*
20	1	1	-1	-1	1	*y20*
21	-1	-1	1	-1	1	*y21*
22	1	-1	1	-1	1	*y22*
23	-1	1	1	-1	1	*y23*
24	1	1	1	-1	1	*y24*
25	-1	-1	-1	1	1	*y25*
26	1	-1	-1	1	1	*y26*
27	-1	1	-1	1	1	*y27*
28	1	1	-1	1	1	*y28*
29	-1	-1	1	1	1	*y29*
30	1	-1	1	1	1	*y30*
31	-1	1	1	1	1	*y31*
32	1	1	1	1	1	*y32*

Table E.2: H-points - Result of Full Factorial Design

	X	Y	Z	Torso
1	41,6	- 85,2	1,8	5,4°
2	40,1	- 85,3	-0,1	5,7°
3	42,5	- 85,3	3,7	5,2°
4	40,2	- 85,3	1,6	5,7°
5	40,5	- 85,1	5,7	5,3°
6	32,3	- 85,1	10,3	6,1°
7	41,2	- 85,2	7,4	5,3°
8	32,6	- 85,1	11,8	6,1°
9	40,9	- 85,3	0,3	5,4°
10	39,4	- 85,3	-2,2	5,7°
11	41,9	- 85,4	2,3	5,3°
12	39,8	- 85,4	-0,3	5,7°
13	39,7	- 85,2	4,3	5,4°
14	31,5	- 85,1	8,2	6,1°
15	38,6	- 85,3	6,0	5,7°
16	32,0	- 85,1	9,9	6,1°
17	41,7	- 85,0	7,3	5,3°
18	38,7	- 85,1	6,7	6,4°
19	38,3	- 85,0	10,6	6,4°
20	39,2	- 85,2	7,8	6,4°
21	38,1	- 84,9	8,7	5,6°
22	38,7	- 85,2	16,2	6,4°
23	38,7	- 84,9	10,1	5,6°
24	33,2	- 85,1	17,5	6,5°
25	40,7	- 85,0	6,3	5,4°
26	38,2	- 85,1	4,7	6,3°
27	41,5	- 85,1	7,9	5,3°
28	38,8	- 85,2	6,3	6,4°
29	33,3	- 85,0	10,9	6,9°
30	32,5	- 85,1	14,4	6,4°
31	33,9	- 85,0	12,6	6,9°
32	32,7	- 85,1	15,9	6,5°

These were the H-points that the Full Factorial Design resulted in. Note that these numbers are with respect to a nominal scale, due to confidential information.

F

Appendix: Validity Analysis Setup and H-points

The Validity Analysis Orthogonal Array Design Setup is presented here, together with the H-points that the Validity Analysis resulted in.

Table F.1: 8-run Validity Analysis matrix.

	A	B	C	D	E	F	G	
1	-1	-1	-1	-1	-1	-1	-1	*y1*
2	-1	-1	-1	1	1	1	1	*y2*
3	-1	1	1	-1	-1	1	1	*y3*
4	-1	1	1	1	1	-1	-1	*y4*
5	1	-1	1	-1	1	-1	1	*y5*
6	1	-1	1	1	-1	1	-1	*y6*
7	1	1	-1	-1	1	1	-1	*y7*
8	1	1	-1	1	-1	-1	1	*y8*

Table F.2: H-points - Result of Validity Analysis.

Comfort, large difference	X	Y	Z	Torso
1	37,9	-85,4	9,3	6,2°
2	31,1	-85,1	24,3	6,8°
3	30,5	-85,0	25,9	6,9°
4	38,2	-85,4	14,0	6,2°
5	38,1	-85,2	16,3	6,4°
6	31,1	-85,3	21,9	6,2°
7	30,1	-85,3	19,3	6,3°
8	37,0	-85,0	15,5	6,4°
Comfort, small difference				
9	38,4	-85,3	-3,4	5,9°
10	32,1	-85,1	12,4	6,4°
11	32,2	-85,1	14,1	6,4°
12	38,7	-85,4	-2,4	5,9°
13	38,5	-85,1	4,6	6,3°
14	36,0	-85,2	8,3	6,4°
15	30,4	-85,2	5,3	6,1°
16	37,7	-85,0	2,8	6,3°
Sport, large difference				
17	45,7	-85,3	6,7	5,2°
18	42,8	-85,1	15,1	5,4°
19	42,9	-85,1	15,7	5,3°
20	47,2	-85,1	13,6	5,3°
21	45,9	-85,0	12,8	4,9°
22	45,3	-85,1	17,1	5,3°
23	44,1	-85,2	14,0	5,2°
24	45,2	-85,0	12,3	4,9°
Sport, small difference				
25	44,5	-85,3	-3,8	5,2°
26	41,6	-85,1	11,2	5,6°
27	50,5	-85,1	6,4	5,3°
28	44,9	-85,2	2,1	5,4°
29	44,7	-85,0	2,5	5,2°
30	44,5	-85,1	9,1	5,3°
31	42,7	-85,3	4,0	5,2°
32	44,5	-84,9	7,2	5,3°

Due to confidential information, the results of the H-points are described from a nominal value of 0, which differ from the actual coordinates that the simulations gave.

G

Appendix: Foam Parameter Study Setup and H-points

The Foam Parameter Study with Full Factorial Design Setup is presented here, together with the H-points that the Foam Parameter Study resulted in.

Table G.1: 24-run Foam Parameter Study matrix.

Textile 1	A	B	C
1	-1	-1	-1
2	1	-1	-1
3	-1	1	-1
4	1	1	-1
5	-1	-1	1
6	1	-1	1
7	-1	1	1
8	1	1	1
Leather 1	A	B	C
9	-1	-1	-1
10	1	-1	-1
11	-1	1	-1
12	1	1	-1
13	-1	-1	1
14	1	-1	1
15	-1	1	1
16	1	1	1
Leather 2	A	B	C
17	-1	-1	-1
18	1	-1	-1
19	-1	1	-1
20	1	1	-1
21	-1	-1	1
22	1	-1	1
23	-1	1	1
24	1	1	1

Table G.2: H-points - Result of the Foam Parameter Study.

	X-coordinate	Y-coordinate	Z-coordinate	Torso angle
1	29,6	-85,1	11,1	6,5°
2	31,3	-85,1	10,2	6,4°
3	30,1	-85,1	12,9	6,4°
4	31,6	-85,1	12,2	6,5°
5	30,1	-85,1	11,1	6,4°
6	31,9	-85,1	10,2	6,3°
7	30,6	-85,1	12,9	6,4°
8	32,2	-85,1	12,1	6,4°
9	34,6	-85,0	1,4	6,5°
10	37,2	-85,0	0,4	6,3°
11	37,5	-85,0	2,5	6,3°
12	37,6	-85,0	2,6	6,4°
13	34,0	-85,0	1,8	6,5°
14	37,5	-85,0	0,5	6,3°
15	35,6	-85,0	3,3	6,4°
16	37,9	-85,0	2,4	6,3°
17	34,6	-85,0	1,4	6,5°
18	37,1	-85,0	0,5	6,3°
19	35,2	-84,9	3,4	6,5°
20	37,5	-85,0	2,6	6,4°
21	35,0	-85,0	1,4	6,4°
22	37,5	-85,0	0,5	6,3°
23	35,5	-85,0	3,3	6,4°
24	37,9	-85,0	2,5	6,3°

Due to confidential information, the results of the H-points are described from a nominal value of 0, which differ from the actual coordinates that the simulations gave.