Investigation of new concepts of Active Shutters for Battery Electrical Vehicles

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Abstract

Prior developments of Active Shutters focused on Internal Combustion Engine vehicles while the market of Battery Electrical Vehicles is raising.

This project aims at selecting and weighting the requirements on the Spoiler Active Shutters in the case of the Battery Electrical Vehicles as well as investigating new concepts adapted for their powertrains. Moreover, it carries out the first House of Quality with two levels carried out at Volvo with an aim at testing the quality tool and its process to improve it.

In the wake of a market, societal and technical analysis, the ranking of the requirements on the system has been done through the use of a House of Quality linking the Business requirements on the system which resulted in the prioritization of twenty requirements. Moreover, some feedback has been provided to the Hardware Quality Team of Volvo to present the process followed by the project team.

The project was followed by a concept development phase, including a problem clarification step, and an iteration of the generation and selection of concepts. The concept generation led to three final concepts, which could represent different potential strategies for the system. The Classic is an optimization of the current shutters developed by Volvo, the Other bolsters the performance of the part by integrating it to the A-Surface of the bumper while the Synergy focuses on the cooling needs during the fast charging by adding hidden air inlets.

Keywords: Active Shutters - Product Development - Design for Six-Sigma - House of Quality - Battery Electrical Vehicle - Volvo Car Corporation

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Last but not least, never underestimate the power of a coffee and kanelbulle after a meeting or simply to fast-charge!

Glossary

Active Grille Shutter (AGS) The AGS is the solutions used to actively control the air flow entering the engine bay in the grille area. xv, xvii, 1, 12, 13

Active Shutter (AS) System controlling the air flow entering the engine bay. 1, 7, 33, 45, 60

Agile Release Train (ART) Primary value delivery construct in SAFe framework. Along with other stakeholders, incrementally develops, delivers, and where applicable operates, one or more solutions to the value stream for the department. (Scaled Agile, 2019). 1, 28

Attribute Leaders (AL) Expert engineers that are responsible for their Attribute Area which generally incorporates the full vehicle, for instance, weight or aerodynamics. 1, 3, 45

Battery Electrical Vehicles (BEV) pure driven electric vehicle with energy stored in an onboard battery pack. 1, 33, 61

Class A-Surface Surface which is seen by the customer. 1, 79

Design Characterise Optimise Verify (DCOV) Gate-System developed by VCC in the spirit of DfSS. 1, 4

Design for Six - Sigma (DfSS) Methodology inspired from the Six-Sigma method and aiming at preventing quality issues to happen from the beginning of the development of the product. 1, 3, 4

Engineering Metrics (EM) Metrics and physical parameters which are used to measure/simulate if the part fulfils the customer needs. 1, 3, 27, 46, 60

Global Technology Development System (GTDS) Gate system created by VCC in order to structure Advanced Engineering projects. It is highly inspired from the Design for Six-Sigma guidelines. 1, 4, 59

House of Quality (HoQ) Quality Tool used in order to link the Customer Needs to the Engineering metrics of the system. 1, 3, 6, 45, 46, 60

Hybrid Electrical Vehicles (HEV) A vehicle that combines an internal combustion engine with an electric propulsion system. 1, 7

Internal combustion Engine (ICE) Is the conventional powertrain utilising the combustion of fuel, to converting into mechanical power.. 1, 7, 33, 34

Noise Vibration Harshness (NVH) Is primarily analyse of whereby the car delivers noise or vibration to the occupants in the cabin.. 1, 8, 60

Original Equipment Manufacturer (OEM) Company that produces parts that may be marketed by other manufacturers. 1, 7, 33, 46, 59, 75

Perceived Quality (PQ) Department at Volvo that is responsible for the appearance of the vehicle, from the material to the geometry appearance. 1

PP Polypropen, polymer created by a combination of alkane (propen). 1, 17, 78

Voice of Customers (VoC) Customer Needs expressed on the system. 1, 3, 25, 46

Volvo Car Corporation (VCC) A Swedish car manufacturer, with headquarters and R&D in Gothenburg (Sweden). 1, 33, 46

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1 Introduction

One of the significant challenges of the automotive industry is the growing customer demand for more energy-efficient vehicles. One system whose objective is to contribute to this efficiency is the Active Grille Shutter (AGS).

The history of the system can be traced back to 1930s when Rolls Royce was the first vehicle manufacturers to adopt it. The central reason back then was for thermal heat-up advantages. Since then the functionalities of AGS-system have advanced and like today and the main objective is to increase the overall energy economy of the vehicle by balancing the conflicting attributes (Eva, 2011).

The system is positioned in the front of the vehicle and mounted behind the grille and spoiler openings. The functionality is to regulate the airflow entering the engine bay by a damper function. It can then provide airflow when there is a cooling need for the vehicle. Likewise, the AGS-system enables sealing of the frontal area when there is no need for under-hood airflow. This sealing of the front entails a reduction of the aerodynamic drag and will improve the overall energy economy of the vehicle. Based on research and open source publications, the effect of the AGS-system is a very cost-efficient way to reduce aerodynamic drag. The overall result is dependent on several factors, but the main drivers are total frontal area, vehicle speed, and ambient temperature. Calculations and wind tunnel measurements have confirmed that a closed AGS-system at a vehicle speed of 105km/h reduces the drag by 3% (Eva, 2011)(Li et al., 2018).

1.1 Background

The current situation is that a majority of the premium vehicle manufacturers have comparable solutions to regulate the airflow entering the grille- and spoiler openings. The solution used by Volvo Cars (VCC) for their internal combustion engine vehicle (ICE), and hybrid electric vehicle (HEV) is to mount two active shutters between the cooling package and the bumper skin. One for the grille opening and one is for the spoiler opening. This concept is favorable because it is a trade-off for many attributes, due to airflow control, aerodynamics, thermodynamics, and styling. Nevertheless, this is the most common solution in the premium car segment in the main of the markets. However, some provincial laws and regulations govern the usage of AGS. That is the case in the North America region, which implies that VCC and other Original Equipment Manufacturer OEM are not entitled to implement the

AGS-system in these markets yet. This fact highlights that the main reasons for the usage of the AGS-system may be different for each region.

The in-house expertise at Volvo Cars is comprehensive. There is a development- and strategy team responsible for the product and the progression of the system. This team is supported by the in-house technical expertise in various attribute area. Previous developments have been carried out in-house but likewise in cooperation with suppliers.

The trend in the automotive industry lies in the electrification of vehicles. This forecast predicts an expanded market share of both HEV and battery electric vehicle (BEV) (Pereirinha et al., 2018). In this area, Volvo has a high set goal that 50% of the sales volume should be fully electric by 2025. Already in 2019, the first fully electric Volvo vehicle will be launched (Volvo Car Corporation, 2018). The integration of a pure battery electric drivetrain will bring new requests for the shutter-system. The need for airflow in the engine bay will drastically shift due to the thermal changes of the electrified engines. This implementation will result in that the cooling need will probably be less while driving. New requirements will appear, such as how to handle the high heat produced when fast charging the vehicle, or how to seal the engine bay in case of low ambient temperature. Another challenge is that the market trends for BEV are moving towards smaller and smaller openings in the front area. The trend other OEM that has launched BEV is only to apply shutter systems in the spoiler and remove or close the grille opening.

The purpose of this project is, therefore, to investigate what shutter system would be the most suitable concept solution according to the customer needs and specifications of the BEV.

1.2 Research questions

To get the correct focus during the project, it is essential to generate research questions for the project. This step is a way to reflect the purpose of what is the actual need to investigate throughout the project. These research questions have guided the literature review, research design, data collection process, and the research analysis (Bryman and Bell, 2011).

A set of four research questions was formulated at the start of the master thesis. Two are linked to the technology of the active shutter system and two references to the master thesis methodology.

The aim of the first question is to collect knowledge needed to understand the change of requirements between the different drive trains. Therefore the question was formulated as:

- *What are the differences between the battery electric vehicle and internal combustion engine vehicle requirements?*

It is essential to evaluate several concepts of the active shutter system based on the BEV requirements. Established engineering methods will support the assessment.

- *What are the best concepts of active shutters based on the requirements for the battery electric vehicles?*

The outcome of the project is the foundation for evaluating the methods. Due to that the shutter system is a compromise of different attribute areas, and since the needs could be contradictory, the third research question is:

- *How is Design for Six Sigma an enabler for cross-functional collaboration?*

Lastly, to get a higher perception of how iterations could refine concepts, the fourth research question is formulated as:

- *How can iteration loops refine concepts?*

1.3 Aims

The master thesis aims at improving the energy efficiency at the system level of the active shutter system, and further to generate innovative concepts. Besides, the project will also assess the methodology Design for Six Sigma (DFSS) and recommend potential improvements on how VCC implements the methodology. By the end of the project, these results will be achieved:

- The House of Quality (HoQ) will have translated the Voice of Customers (VoC) into Engineering Metrics (EM).
  - Have organised at least ten meetings with various attribute leaders (AL) and expert engineers to understand customer needs and engineering metrics.
  - Provide an analysis of the gathered requirements.

- The project will have generated and assessed at least five different concepts through different iterations.
  - Improve the overall performance of the active shutter system by 20% based on total merit value from a Kesselring matrix (compared to the current concept of active shutters).
  - Include the design team in at least two innovation workshops.
  - Study the potential modulation of the system.

- The project will have acted as a learning facilitator between the attribute leaders and the design team of the system.

  - Organise at least three meetings between the team and various attribute leaders.
  - Present learning for the design team, and introduce the Design for Six Sigma tools used through the master thesis.
  - Rank the Voice of Customer and provide a visualisation tool to help the product design team to prioritise features and requirements.

- The master thesis team will have assessed the tools used throughout the project.
  - Adapt available templates to support the product design team and the department in the use of those tools for the future.
  - Give feedback on the learnings from the House of Quality to the Volvo Cars quality department for continuous improvement.

1.4 Methodology

The process has been designed based on the synergy of the competences of the team members in the master thesis project. To ensure the quality and reliability of the concepts developed, it was decided to follow some of the tools that are advocated by the guidelines of Design for Six Sigma guidelines (DFSS). In particularly the internal VCC process, which is the DCOV method (Appendix A).

To help engineers working at VCC to structure their Advanced Engineering projects (AE) according to DfSS, VCC is using the Global Technology Development System (GTDS). The GTDS is a four-Stage gateway review framework which reflects DfSS and intends to secure those essential milestones are delivered. The stages are Technology Kick-Off (TKO), Technology Strategy (TS), Concept Readiness (CR) and Application Readiness (AR). Within these stages, several results need to be approved by stakeholders in order to for the project to move on to the next gate, an example of these deliveries can be seen Figure 1.1.

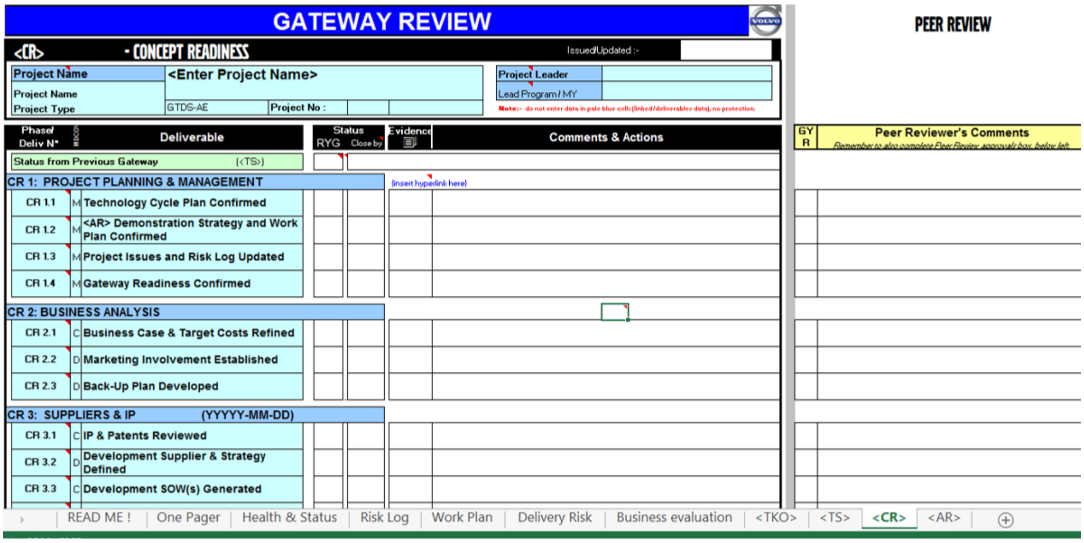


Figure 1.1: Caption of the Technology Strategy phase detailed earlier

Based on both the scope and time constraints of the project, a unique methodology has been developed. This process has been inspired by the first two gates in GDTS (TKO & TS). However, it focuses mainly on delivering milestones within this that support the project aims and scope. Based on those results, design iterations will be performed and evaluated, as seen in Figure 1.2.

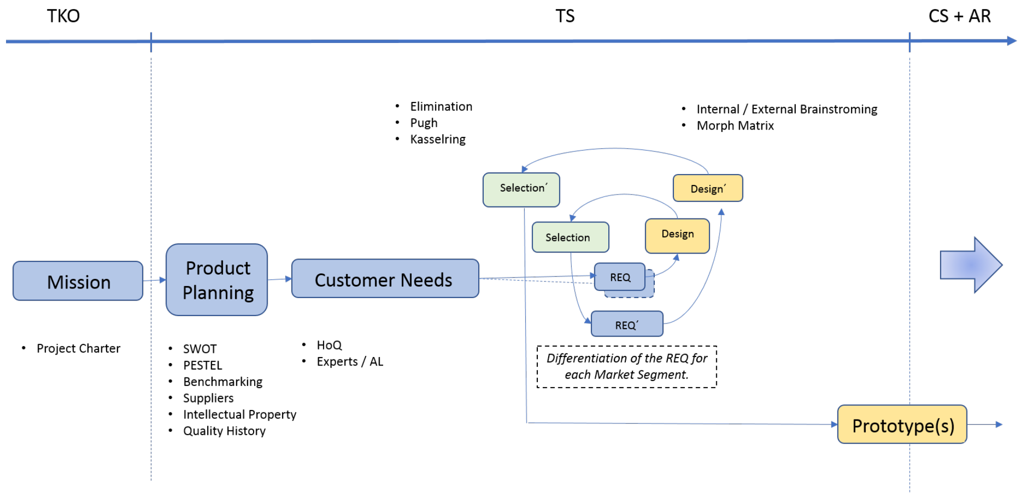


Figure 1.2: Process of the Master Thesis

All the tools and techniques used in the project are described thoroughly in Section 3 and 4. The process in Figure 1.2 summarises the project and presents the four main steps of the project: Mission, Product Planning, Customer Needs, and Concept Generation.

The project started with a mission gate. In this phase of the project, three main results were expected to be delivered. It contained a Gantt-schedule, a project charter (Appendix B) and an initial project feasibility study aims to for example evaluate possible risk, available resources, and project business impact.

In the second Product Planning gate, several milestones were delivered in terms of various tools and investigations. As shown in Figure 1.2, the gate consisted of a literature review, SWOT-, PESTEL analysis, benchmarking-study, quality analysis, P-diagram, first contact with suppliers, and an intellectual property investigation.

The third gate Customer Needs was a comprehensive gate. During this phase, the goal was to identify the customer needs and to be able to prioritise them corresponding to each other. An extensive amount of experts interviews were conducted with different attribute leaders, the business owner, and expert engineers. This data was the material for the house of quality (HoQ), which is the fundamental delivery of the Customer Needs gate.

The last gate Concept Generation was based on the results of the Customer Needs gate. The first step was to organise both internal and external brainstorming sessions at VCC. This approach was pursued in order to accumulate many ideas to have as many inputs as possible for a morphological matrix. The generated concepts from the morphological matrix were then judged objectively by an elimination-, Pugh-, and Kesselring matrix. This review was done in consultation with the departments of expert engineers and attribute leaders.

1.5 Limitations

The master thesis is delimited to just focusing on the challenges for active shutter systems for battery electric vehicle. Only solutions for BEV will be considered in the investigation (eliminating HEV of the scope). Due to time and resource constraints, the focus of the project is to generate concepts and not to focus on the detailed design.

Furthermore, the master thesis will not include the control of the shutter system since that function is connected to another department responsibility. Moreover, because the project only evaluates requirements and generates new ideas, there will be no detailed material-, assembly- or life cycle assessment.

2

Study Objects & Associated theories

This Section describes the Active Shutter, which is the system which is investigated. As explained earlier, it is linked to a significant number of Attribute Areas, where the most prominent ones will be presented in detail.

2.1 Description of the System

As described in Section 1.1, the active shutter (AS) system is positioned in the front of the vehicle. The system is connecting the bumper openings with the cooling pack. The position and function are illustrated in Figure 2.1 and 2.2. All the functions of the shutter system are found in Appendix C. The dependencies of the respective attribute areas are described in detail in Section 2.2.

Figure 2.1: CrossSection of the Front of a vehicle, where the active shutter systems are marked in red

In the case of ICE- and HEV vehicles, it is standard among the OEM to have both a grille- and spoiler shutter. The grille shutter is located above the top crash beam, and the spoiler shutter is often situated underneath the crash beam. This concept is visualised in the cross-section view of a vehicle in Figure 2.2.

In the case of BEV, Volvo has not yet delivered a car to the market. Based on the market trends and engineering judgments in-house, and looking at the current BEV on the market (for instance Tesla or Nissan Leaf), the spoiler shutter is likely to be the only opening for the future Volvo BEV while the grille would be closed.

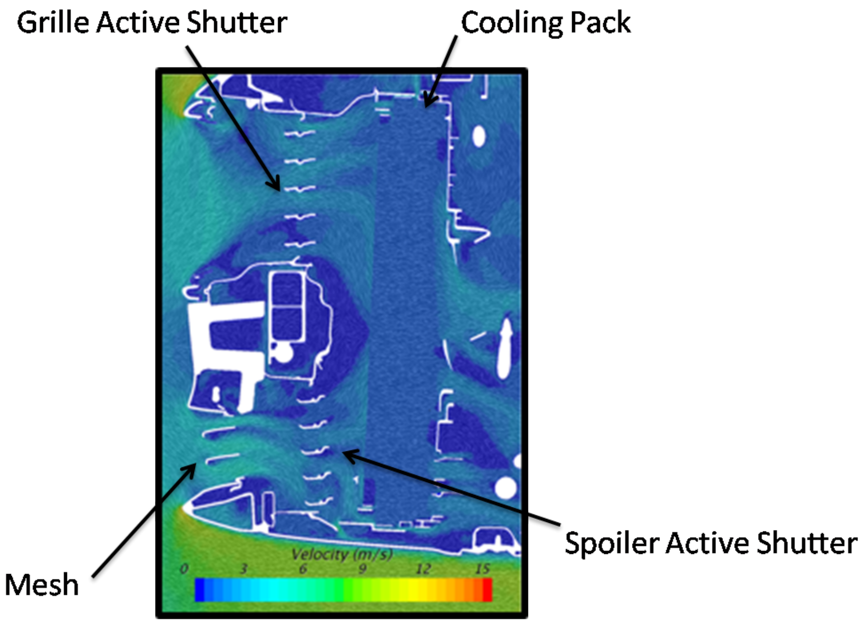


Figure 2.2: Detailed cross-section simulation results of the front system of an ICE-vehicle with both grille- and spoiler shutters. (Johansson, 2019)

As mentioned in Section 1.1, the primary purpose of the shutter system is to balance the different needs such as reducing the vehicles aerodynamic drag, improving the cooling performance, increasing engine efficiency in cold environments and reducing Noise Vibration and Harshness (NVH). Since several departments and functionalities are reliant on this air flow, many stakeholders are affected by the design of the shutter system.

The robustness of the system is high, which can be seen by studying the quality history of Volvo cars' previous projects. The shutter system has a small rate of customer complaints and warranty claims. It is essential for the system to withstand contamination such as wading, dust, and snow. However, there are a few cases of snow and ice locking issues in the cold markets, which lead to critical error-states for the system.

Even if the system does not have any active safety function, its position in front of the vehicle adds a safety dimension in the design due to pedestrian safety. Moreover, it is also vital that the component does not damage any surrounding elements in the case of low-speed crashes. This scenario is the justification for the insurance cost of the vehicle, also called the Allianz tests. Last but not least, since the shutters may be apparent for the end-customers, it is essential to evaluate aestheticism and perceived quality during the design process.

The actual shutter system contains several components which can be seen in Figure 2.3 that shows the grille shutter for the Volvo XC40. The figure highlights the five different sub-systems: the frame (or Housing), the vanes, air-guide (Soft Plastic, TPE lips), the actuator, lever, and linkages.

Figure 2.3: AS used for the XC40

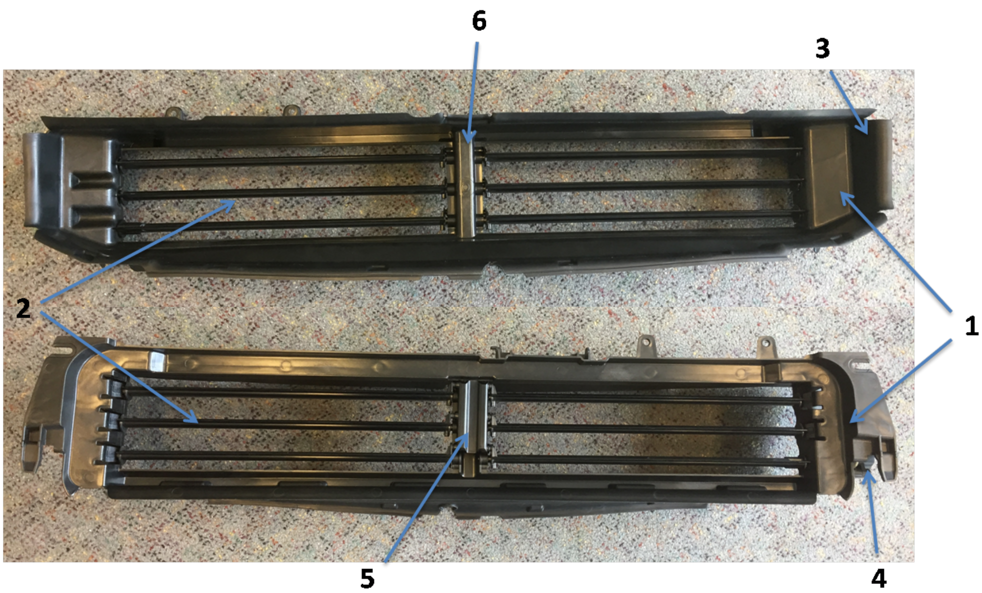


Figure 2.4: AS used for certain projects - here for academical purposes

- *The frame* has the central function of being robust and supporting the other components; in some cases, it can also be a part of the vehicle front structure. The material used for the housing is in general Polypropylene filled with glass fibers (PP+30GF) (1). The central part is a included in the housing (6).

- *The vanes* are the moving part in the shutter system, and they serve as a damper function into the engine bay. The vanes are usually mounted in two horizontal arrays to be sealed against each other in closed position. By rotating 45 degrees, the system is entirely open. The number of vanes depends on the cooling need and vehicle packaging space. The material choice may differ due to stiffness needs or cost; the material used is Polypropylene filled with glass-fibbers (PP+30GF) or Poly-Amide filled with glass-fibers (PA + 30GF) (2).

- *The air guide* has the function of avoiding leakages around the system as well as guiding the air between the bumper skin and shutter. In some cases, an additional air guide is also used between the shutter and the cooling pack to utilise the airflow at its maximum and avoid leakages. This component is often produced in soft plastic materials such as thermoplastic elastomers (TPE) (3).

- The principal function for the *actuator* is to rotate the vanes. The activator is in best cases located outside of the housing to avoid obstructing the air flow. The control of the activator can be done in multiple steps or be more digital (fully open or closed). Design parameter is the torque of the activator, but this needs to be optimised based on the length and fragility of the vane (4).

- The last components in the system are *the lever and linkages*. The linkage between the vanes is highly dependent on the shutter concept. In the XC40 the linkage is placed in the outer frame (5).

2.2 The different Attribute Areas

This section gives a broad understanding of some of the main attribute areas affect the AS design.

2.2.1 Aerodynamics - Improve Energy Efficiency

- What is Aerodynamics ?

Aerodynamics is the knowledge of air flow and its interaction with a solid object, which will result in a flow field and forces (Katz, 2016). The aerodynamic profoundly influences the vehicle dynamics with directional stability, crosswind sensibility, aerodynamic lift- and side forces. Furthermore, aerodynamics significantly affects the performance by aerodynamic drag, which in turn affects the vehicle's fuel economy, range, and acceleration (Sälström). The aerodynamic department at VCC is responsible for making requirements on the car's design, so it is as aerodynamic as possible. The department performs both advanced simulations and physical wind-tunnel testings.

- Basics of Aerodynamics

The following two equations defined a simplified illustration of the vehicle's road load resistance (Alaa E. El-Sharkawy, Joshua C. Kamrad , Todd H. Lounsberry, Gary L. Baker & Sadek S. Rahman, 2011):

$$F_{veh} = F_{roll} + F_{aero}(V^2) \tag{2.1}$$

Where F_{veh} is the resisting force working corresponding as the vehicle motion, $[V]$ is the vehicle speed km/h F_{roll} is the rolling resistance and F_{aero} is aerodynamic drag force.

$$F_{aero} = \frac{1}{2}\rho U^2 C_D A \tag{2.2}$$

Where F_{aero} is aerodynamic drag force $[N]$; ρ is the density of ambient air $[kg/m^3]$; C_D is the drag coefficient ; A is the projected frontal area $[m^2]$ and U is the speed of the vehicle $[m/s]$.

Research done by (Katz, 2016) concludes that the effect of F_{aero} and resistance forces are growing exponentially with the vehicle's speed while the F_{roll} stays almost constant. To decrease the energy consumption of the vehicle, it is then critical to reducing the F_{aero} effect at higher speeds. Provided that the speed and density of ambient air are fixed, the design parameter used by vehicle manufacturers is C_DA. Both of these factors could be viewed as design parameters, particularly the variable C_D. The drag coefficient C_D is the vehicle configuration by on the aerodynamic sleekness. The conclusion is that in order to minimise C_D, it is advantageous to construct shapes wing shapes and avoiding flat surfaces in the airflow (Katz, 2016).

- In the case of the AS

As described earlier, there is a consistent trade-off between the aerodynamic and thermodynamic in commercial vehicle development. An optimal aerodynamic design would be a wing-shaped vehicle, minimising the stagnation force in the frontal area as well as the turbulent air in the rear. However, that sort of design is not reasonable in today's commercial vehicle manufacturing. The shutter systems benefit the redirection of airflow from going within the vehicle engine bay, which then decreases the overall drag coefficient. Open source research and internal VCC documentations, estimations indicate that the shutter system improves the C_DA between 0.03-0.06 depending on the car model (Alaa E. El-Sharkawy, Joshua C. Kamrad , Todd H. Lounsberry, Gary L. Baker & Sadek S. Rahman, 2011) (Sälström). Additionally, in the BEV case, the battery size could be reduced for the same performance, which a significant impact on the total cost of the vehicle and drive costs for Volvo (Sälström).

To put this in relationship with fuel economy experiment carried out in-house covering the New European Driving Cycle (NEDC), the AS brings an improvement of 1.7% to 2.4% depending on the temperature on ambient air -6°C to +25° C (Alaa E. El-Sharkawy, Joshua C. Kamrad , Todd H. Lounsberry, Gary L. Baker & Sadek S. Rahman, 2011).

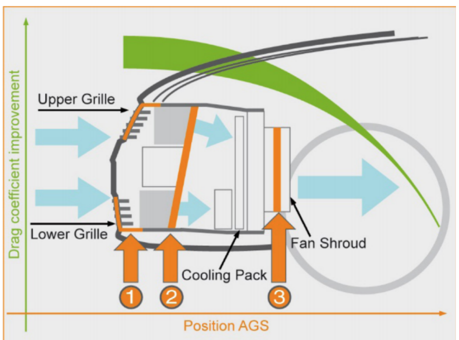
Support on the literature of (ASf, 2014) the main two aspects which affect the influence on the performance of the shutters are:

- The sealing effect around the shutters.

The sealing is mainly related to two factors, the sealing capacity between the vanes as well as the sealing performance of the air guide. These factors are of the highest importance but are challenging to simulate.

- The distance between the shutter system and the bumper skin.

This aspect is related to the design of the vehicle, but the estimation presented in table 2.1 shows a significant improvement in moving the shutter closer to the bumper skin. The presented results in table 2.1 are on placing the shutter system at different distances from the a-surface in an ICE-vehicles. "Position one" correlates with having the shutters at the a-surface. "Position two" corresponds to having the shutters aligned with the crash beam. "Position three" is having one curtain or shutters behind the cooling pack (ASf, 2014).



Position	Δc_d Upper Grille	Δc_d Lower Grille	Δc_d Total
1	0.006	0.010	0.016
2	0.004	0.008	0.012
3	0.007		0.007

Figure 2.5: Drag coefficient improvement versus position of the AGS at a speed of 140 kph (ASf, 2014)

Position	ΔC_d Upper grille	ΔC_d lower grille	ΔC_d total
1	0.006	0.010	0.016
2	0.004	0.008	0.012
3	0.007		0.007

Table 2.1: Drag coefficient enhancement versus position of the AGS at a speed of 140 kph (ASf, 2014)

2.2.2 Thermodynamics - Cooling warm components

- What is Thermodynamics?

From a semantic aspect,"*Thermodynamics*" is the science that deals with heat and work and those properties of matter that relate to heat and work" (Powers, March 2019). Thermodynamics started to be studied before Galileo who developed a water thermometer (Powers, March 2019), and it had a tremendous impact on other scientific fields and the society in general such as the creation of the steam engine who settled down the industrialisation in Europe.

- Basics of Thermodynamics
Thermodynamics is often used through three primary laws, and two of them are going to be described as:

- **First Law of Thermodynamics**: For a system undergoing a process, the change in energy is equal to the heat added to the system minus the work is done by the system. (Powers, March 2019)

$$dE = \delta Q - \delta W \tag{2.3}$$

dE represents the total energy of the system:

$$dE = dE_p + dE_c + dU \tag{2.4}$$

Where E_p is the potential Energy and E_c is the kinematic Energy and U is the Internal Energy.

This first thermodynamics law is similar to the "law of the conservation of mass," noting that this law implies that "nothing is lost, nothing is created, everything is transformed" (Lavoisier, 1789).

- **Second Law of Thermodynamics**: : The entropy of an isolated system can never decrease with time. (Powers, March 2019)
  “Heat cannot, of itself, pass from a colder to a hotter body.” (Clausius, 1879).

The *Entropy* is a "thermodynamic property which provides a quantitative measure of the disorder of a given thermodynamic state" (Powers, March 2019).

Consequently, Thermodynamics deals also with Heat Transfer since it can seen as an Energy Transfer between the two systems. This transfer can be done using several physical principles:

- **Conduction**: "Thermal conductivity is attributed to the exchange of energy between adjacent molecules and electrons in the conducting medium." (Britannica, 2019)
  The Fourier's law of thermal conduction can be used to calculate the local heat flux density:
  $$q = -k\Delta T \tag{2.5}$$
  Where q is the local heat flow density , k is the material conductivity and ΔT is the temperature gradient. [C].
- **Convection**: "In heat convection, the transfer of energy occurs between an object and its environment due to fluid motion. In other words, the heat is carried by a flowing fluid from one place to another." (Powers, 2019) The local heat flux density can be calculated with Newton's convection law:
  $$q_h = hA(T_s - T_f) \tag{2.6}$$
  Where q_h is convective heat on the surface, h is the convection heat transfer coefficient, A is a cross-section of boundary surface, T_s is the surface temperature, and T_f is the temperature of the surrounding fluid. (Powers, 2019)

A quick study of the different thermal transfer shows that the convection heat transfers are more efficient than the conduction transfer (Hébert, 2015). Last but not least, it is critical to highlight the differences between laminar and turbulent flows on the heat transfer provided by those flows.

- In the case of the AS?
The air flow entering through the AS is mainly used to provide air flow to the cooling pack. The condenser is one of the parts used within the cooling circuit to cool the warm elements as in other refrigeration cycles (Hébert, 2015).

The air flow coming from the AS evacuates the heat at the condenser. In order to facilitate this heat transfer, the convection is preferred to the conduction since the lead times are reduced. Even if the condenser is designed to maximise the surface in contact with the air flow, a fan is also added to the system to support the air flow by creating an under-pressure in front of the cooling pack and then sucking air through it.

In the case of ICE vehicles, air flow enters at the front of the car to maximise the pressure of the air flow to optimise the heat transfer. The area of air-entry is also used to increase the air flow at the cooling pack.
On the other hand, BEV needs air flow when standing still for fast charging. This means that the heat transfer is mostly done by conduction ($Speed_{AirFlow} = 0m.s^{-1}$).

In order to keep the convection effect, the air must gain speed; therefore, the fan is used.

On the other hand, fast-charging aims at reducing the time needed to charge the vehicle, which means increasing the energy transfer in a shorter time, leading to an increased need for cooling. Consequently, fast-charging is considered as a bottleneck for the thermodynamic needs of the BEV.

The differences in fluid properties between the laminar and turbulent fluids call for aero-shaped surfaces. Consequently, thermodynamics prefer to have a clear path for the air with minimal air-obstruction.

2.2.3 Safety - Protecting what matters

- What is safety?

The Swedish government has a "Zero Vision" in fatalities on Swedish roads, as a part goal of the number of deaths in traffic must not exceed 220 in 2020. The official Swedish statistics for March 2019 was ten people were killed, and 1244 people were injured (134 severely- and 1110 slightly injured) in traffic which is barely a fraction of the global number (Agency, 2019). So this entails both vehicle manufacturers and governments to work actively with this question.

A road safety partnership between some of Europe's states and car manufacturers is Euro NCAP (European New Car Assessment Programme). The goal of this alliance is a safer traffic environment, as well as fewer personal injuries in connection with accidents. The practical activity consists in principle of a crash test where the car is rated according to how well it protects adults, children, pedestrians and safety aids. From these tests, the car then gets a total rating, also 1-5 stars (NCAP, 2019).

At VCC, safety has been broken down into two categories; Active safety (to avoid accidents or reduce velocity before impact) and Passive safety (to reduce the injuries on the pedestrian or occupants by acting on the forces, bending moments, accelerations during an accident).

- In the case of the AS?

One of the cornerstones for the Euro NCAP rating is the Protection of the pedestrian. The shutter system influences on the upper- and lower leg impact, and the test is carried out to estimate the potential risk of bone or pelvis injuries in case of a pedestrian crash. The outcome of the test is mostly dependent on the vehicle front structure design, but it is also affected by the stiffness of the shutter system and likewise the distance between the bumper and shutter.

The shutter system also influences safety requirement for the Allianz test. This test is designed to determine the cost of the Insurance for the cars' owners and is based on the set-up of a low-speed crash. In that case, the shutter system should not destroy any more expensive surroundings components. By passing this tests the vehicle will get a lower insurance fee.

2.2.4 Styling/Perceived Quality - Boosting the Scandinavia style

- What is Styling and Perceived Quality?

Styling is in charge of the appearances of the vehicle (inside, outside surfaces). This design involves the shape, material, and proportions used for the vehicles.

Perceived Quality (PQ) is in charge of making sure that all the surfaces seen by the consumer have a premium look. PQ often helps Styling to establish the requirements on the vehicle or parts to make sure that the final product stays conform to Styling wishes.

As highlighted in Volvo's official documents before-mentioned as the BRand Attribute Guideline (BRAG) (Ariño, 2019), styling is a critical attribute. Since Volvo operates as a Premium OEM, and feelings or emotions are highly linked to the car's appearance.

Generally, Styling's freedom is essential to give them the liberty to create the surfaces and shapes they envision for the future as the brand image.

- Basics of Styling and PQ

Styling and PQ are responsible for:

- the material quality to ensure that there are not visible manufacturing mark (such as injection marks or weld lines).
- the geometry appearance such as flash or gaps. Specific software such as Rd&T can be used to help engineers.
- the illumination to ensure harmony, synchronisation and a premium execution.
- the paint and surface finish.

- In the case of the AS

Due to its position close to the A-Surface, the AS can be seen by the end customer, which automatically implies styling and PQ requirements. In general, the AS should not take attention from the central Volvo's symbols such as Thor's hammer or the waterfall (grille) then even if the AS should not be necessarily hidden, it should be discreet.

2.2.5 Contamination - Protect inner sub-systems

- What is Contamination?

The Contamination department aims at preventing contamination such as dust, snow, or grease from entering the engine bay or more generally inside the vehicle. It also makes sure that the car can function in extreme conditions such as driving in water or driving in snow.

- Basics of Contamination

Contamination issues can be solved by using Design Guidelines gathering the lessons learned and advises to design the systems to prevent from the start the issues from happening.

The material choice can also affect the interactions of the system with the environment. Hydrophilic materials can create interactions with similar materials. By using their polarity, water and other hydrophilic elements can create H-bondings (Figure 2.6) or VanDerWalls interactions spreading them inside or on their surface (T. S. Moore, 2019) (Eduscol, 2019).

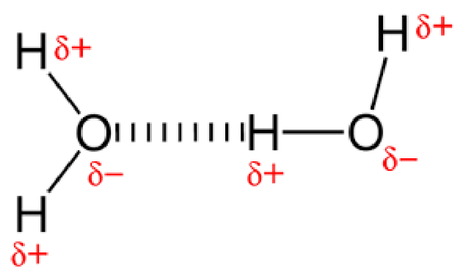


Figure 2.6: Hydrogen Bonding (T. S. Moore, 2019)

- In the case of the AS

As mentioned earlier, the car should be able to drive through water, and hence water-tightness was to be taken into account for the part's design, as well as strength requirements (the pressure of the water).

Since the AS is close to the outer surface of the bumper, it should also resist to snow and other polluting elements coming from the environment. It is critical to mention that those particles and gravels can be very different depending on each country and situation, from the microscopic sand in China, the dust in Arizona or the grease in Russia.

Regarding the material choice, it is possible to limit the interactions between the water and the material by using nonpolar materials such as Teflon or Polypropylene (PP). This choice helps to limit snow packing but tends to slightly increase London Interactions with hydrophobic elements sch as grease (Eduscol, 2019).

Last but not least, the part should prevent the more expensive parts from being hit by stone shipping, such as the cooling pack. This is why the outside mesh and the AS should not let big stones enter the inner engine bay.

2.3 Six Sigma

The Six Sigma methodology aims at making the business processes more robust against variation by using scientific methods for process improvement. The methodology was invented by Motorola at the end in the 1980s as "The Six Sigma Quality Program" as a response to the increased competition against Japanese industry (Yang and El-Haik, 2009). In the 1990s the concept propagated and companies continued launching Six Sigma as a central business strategy. One example is multinational company General Electric that saved millions of dollars by implementing Six Sigma initiatives (Yang and El-Haik, 2009). The basis of six sigma is a structured approach to improve activities in iterative design, with a well defined hierarchical structure, cross-functional teams and standardized problem-solving procedures of models and tools.

However, when mentioning Six Sigma it is commonly connected to the DMAIC-cycle, a methodology that consists of five different phases Define, Measure, Analyse, Improve and Control. This approach is beneficial to handle the organization's quality issues when a process or product is already in the current business and is not satisfying customer needs or needs to be streamlined.

In the effort for zero defects process or product, the mathematical definition used is Sigma, which stands for the standard deviation of the data set. The ambition to achieve a 6-Sigma process which corresponds to 3.4 defects per million units (DPMO), This facilitates great process consistency and low variation (Brue and Launsby, 2003). To prevent variation and defects from happening and being visible by the end-customers, DfSS is a methodology that is acquired to develop businesses processes to prevent errors in new development.

2.4 Design for Six Sigma

To produce "Six sigma performing" products, Design for Six Sigma is a systematic methodology to establish robust products according to customer needs. This methodology provides tools that aim to diminish problems and defects before a product is launched by integrating the customer preferences within the development process, which results in problem prevention. 45% of new product development are killed or fail to give sufficient commercial revenue (Brue and Launsby, 2003). Many of these failures are due to inadequate demand analysis or product defects and could be prevented with a method like DfSS.

Design for Six Sigma is an approach for developing new or existing products to satisfy or exceed customer demands and expectations. DfSS in a development process is not a replacement for the traditional quality work and improvement theories. It should rather be interpreted as a sub-component to combine within usual development activity. Unlike the problem-solving standardise DMAIC-cycle, DfSS has no settled design so it needs to be adapted to the company situation. The choice of

DfSS method and arrangement is depending on the business situation, to show some of the selection of versions (Brue and Launsby, 2003):

- DMADV—Define, Measure, Analyze, Design, and Verify
- DMADIC – Define, Measure, Analyze, Design, Implement and Control
- DCCDI—Define, Customer, Concept, Design, and Implement
- DCOV—Define, Characterize, Optimize, and Verify

Because VCC practices the DCOV-version and further that the project is partly coached by Master black belt vehicle hardware, this process has been selected to be followed. Every tool used in the project will be described in the following chapters, but briefly introduction tools and how they are connected to each phase:

- **Define:** The mission of the Define phase is to integrate customer needs and product. This activity accommodates to define customer expectations are as well as creating support to the design work. The key deliveries in this phase are a Project Charter, Quality Function Deployment (QFD), Interviews, and Quality Data Analysis of real usage and warranty data.
- **Characterize:** During this phase, the project should have cascaded the customer specifications and also delivered a robust system. The key activities are Brainstorming gatherings, Benchmarking, Value Analysis, Boundary Diagram, Pugh Concept Selections, and primary Failure Modes and Effects Analysis (FMEA).
- **Optimize:** In the third phase, the product should be reliable with a robust design by minimizing the effect of noise factors. Further, a design verification plan should be in place as well as optimization experiments on the system. Tools in this phase are P-diagram, robustness and reliability checklist, noise factor management, proper FMEA, and optimization investigations like design of experiment (DOE).
- **Verify:** Last phase verifies that tasks done in previous phases have been beneficial and that the product design is reliable, robust, and optimized. Tools confirming that is Design verification plan, Long-term process capability, and System or sub-system testing.

3

Project Approach & Methodologies

This section presents the project approach followed for this project and gives a brief understanding of the methodologies used through it and explains how they have been adapted to fit.

3.1 Quality Analysis of the system

The Parameter Diagram (P-Diagram) is a standardised tool which illustrates the inputs of the system to the desired outputs of the system. The process also considers non-controllable parameters and how they influence the design of the product. The P-diagram is an excellent method for the design and quality team to brainstorm in order to understand the system and create a robust design. The goal of the process is to transfer the whole input signal into the response functions. The P-diagram scheme is displayed in Figure 3.1, but it is divided into in five subareas;

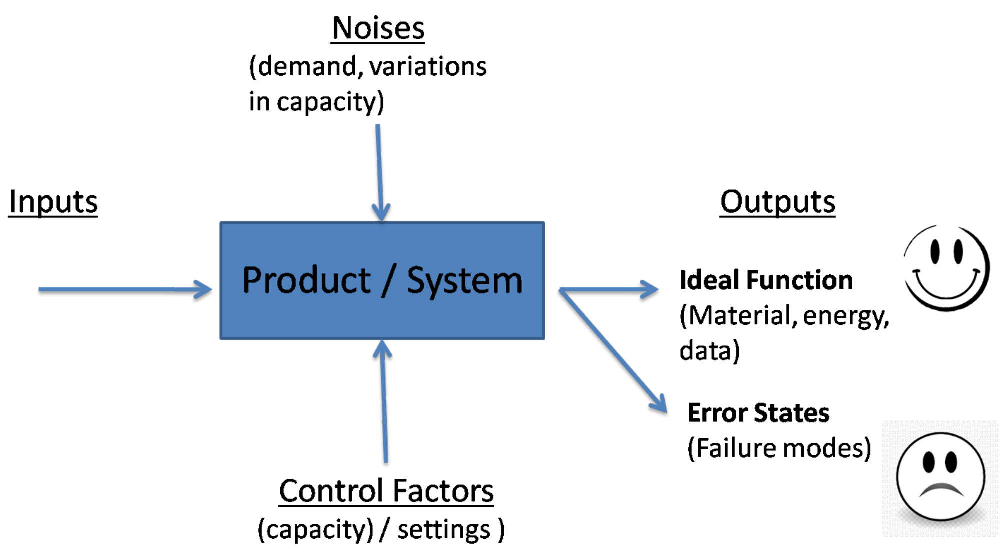


Figure 3.1: Schematics for Parameter Diagram (B.Bergman & B.Klefsjö, 2010)

- The **Input Signal** is the energy that is going into the design of the system to achieve the functionality of the commodity. An input signal for the system could be torque or speed.

- The **Control Factors** are the system configuration parameters. The design team establishes them, examples are material selection and number of moving part.
- The **Noise Factors** are the elements which can affect the system but are not under the control of the design engineer. If these factors are not identified and taken into account in the design, the robustness of the system will be affected. There are five characters of noise factors;
  - *Piece to Piece variation;* is related primarily to the manufacturing of the product; examples of these factors could be assembly-, dimension- and torque variation in assembling.
  - *Change Over Time;* this is the expected wear of the materials in the system. Usually, if these parameters are detected, designers can simulate and predict these circumstances. Typical factors are ageing, fatigue or wear out of material.
  - *Customer Usage;* Probably the most challenging element in distinguishing is the customer usage of the system. The customers may manage the system unpremeditated which is hard to predict; common factors could include extreme customer environments or incautious usage.
  - *External Environments Impact;* are the factors that identify in what environment the system has to perform, these regularly correlates to customer usage category. Examples of factors could be water, vibration, and humidity.
  - *System Interactions;* they are the noise factors that are how the designed system function with additional systems is interacting with, which is very important and considered in vehicle development.
- **Ideal Response Functions** are the intended function-outputs of the system. In a well-designed system, this signal correlates to the input signal without being affected by the noise factors.
- **Error State** is the classification of the internal decline of effectiveness or unsatisfactory system output.

3.2 Market, Societal and Technological Analysis

Before developing any new concepts, it is critical to start with a market and societal analysis to assess the current products and catch market trends.

3.2.1 Market and Societal Analysis

To understand the potential of this project, a **SWOT** analysis was carried out. This investigation intended to recognise the Strengths, Weaknesses, Opportunities, and Threats of this project.

Very different sources can be used to find the information needed. The experience of the stakeholders and the amount of data available in-house can, for instance, give an idea of the amount of knowledge available in-house. Moreover, a comprehensive benchmark can assist in finding out if any competitors may endanger the project outcome. The results are described in section 4.1.

The **PESTEL** analysis aimed at recognising the Political, Economical, Societal, Technological, Environmental and Legislative trends that may affect the project (K. T. Ulrich & S.D.Eppinger, 2012).

This analysis is even more critical in the case of an AE project since the concept would be used in the future and not in the current state. To find accurate information it is critical to search in sources that try to forecast the future such as government reports, Volvo's internal strategies, and forecasts or trends for patents. Moreover, the customer needs are also scattered among all the Attribute Areas before they forward it on the part's designs; so it is critical to include what they can foresee in their area of the attribute. The results are described in Section 4.2.

3.2.2 Technological Analysis

To get an impression of the current market and trends an iterative benchmark process has been completed. This was carried out by strategically examining benchmarking tools for competitors who provide related products or products with comparable functionality (K. T. Ulrich & S.D.Eppinger, 2012).

The initial search for products aimed at achieving a broader view of the current market and discovering possible solutions. This is why it targets the active grille- and spoiler shutters in combination with a particular focus on BEV.

Since competitors' products are highly confidential, it can be of interest to monitor their Intellectual Property, watch their websites or users' videos online. A2Mac1, a benchmark website can also be used to have details on the parts but contains a limited selection of cars. Moreover, in February 2019 a European showroom had the purpose to disassembled vehicles of competitors. This fair was also an opportunity for the master thesis team to forward questions to the department's representatives engineers who visited the show. Last but not least, it has also been possible to introduce prototypes and mock-up presented by the suppliers.

To give a broader view on the potential solutions, the team also considered other domains such as the "regulation of air flow in Heat Pumps" or for "AC in the building sector." The purpose of this part of the benchmark was to investigate how current products help users to manage airflow and what technologies are used.
Furthermore, Volvo has access to surveys sent to Volvo's and competitors' consumers to know what they enjoy and not regarding their cars. This results can be used to find out if there are particular characteristics that the shutter system should have

by taking the VoC immediately into account.

This benchmark was used throughout the master thesis project and have been updated through the project based on new releases or the adding of new fields. In the specific case of this project, it is not possible to test the physical parts of Volvo's competitors then it was necessary to deal with CAD files.

The initial **patent search** aimed at investigating alternative technologies used which could be interesting for this project. This review can also be used to measure the rate of patents filed within the field over the last decade to find the actors or see trends, and investigate what Ulrich and Eppinger call the Freedom-to-Operate (FTO) when developing the product (K. T. Ulrich & S.D.Eppinger, 2012).

To do so, Google Patents was used to get an overview of the international patents by using adequate keywords. Again, the research can be done but including additional fields such as the airflow control for trains and busses to investigate solutions fulfilling similar functions and needs. Moreover, additional support was provided by the IP responsible for the Exterior Front Department at VCC to provide us guidelines and methods to search for and protect the master thesis IP rights.

3.3 Quality Function Deployment

Quality Function Deployment (QFD), is a comprehensive approach to facilitate an unambiguous structure in new product development. QFD originates from Total Quality Control (TQC) projects in Japan in the early 1960s. According to (Cristiano et al., 2000) the two main drivers for QFD development were to make sure that the customer's requirement is the highest priority in an early stage product development and design. Secondly, to be able to present a control chart before initial manufacturing, QFD is designed to focus on the features of a product or service from the customers perspective. The method helps breaking down the customer needs into engineering metrics for the development process, and then prioritises the importance of each VoC. This process is carried out by tables, interrelationship matrices, competitor analysis and establishes clear objectives for the developed product or service.

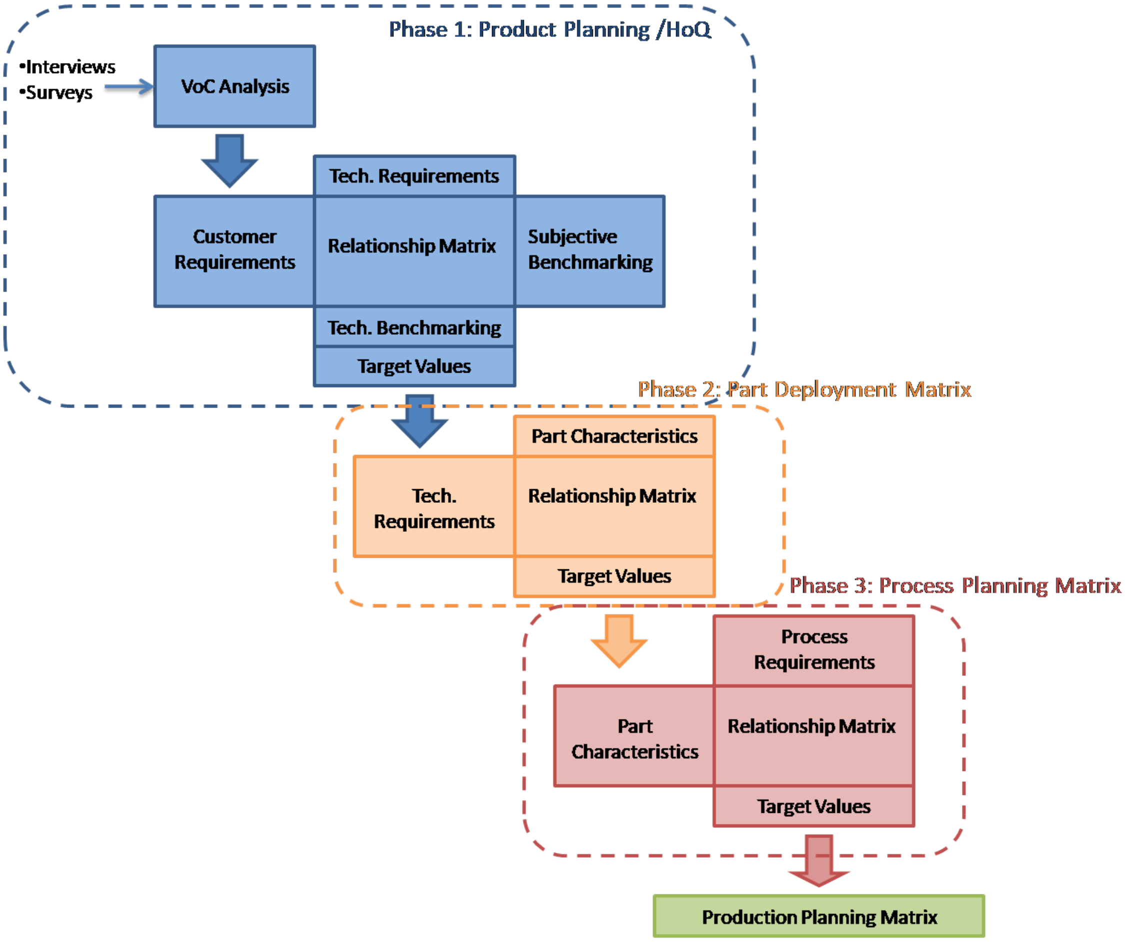


Figure 3.2: Four-Phase Model of the Quality Function Deployment adapted from (B.Bergman & B.Klefsjö, 2010)

As seen in Figure 3.2, the method consists of four matrices process: Product Planning, Part Deployment, Process- and Production Planning. This whole process is driven and based on the Voice of the Customer (VoC). The combination with a waterfall sequence, the QFD method ensures that the customer needs only encourages the development process, Figure 3.2 demonstrates this process. The result of the initial matrix is weighted Engineering Metrics that is the base for the next matrix, for example between phase one and two, "technical requirements" progress from metrics to be the customer needs. The specific process followed is presented in Figure 3.3.

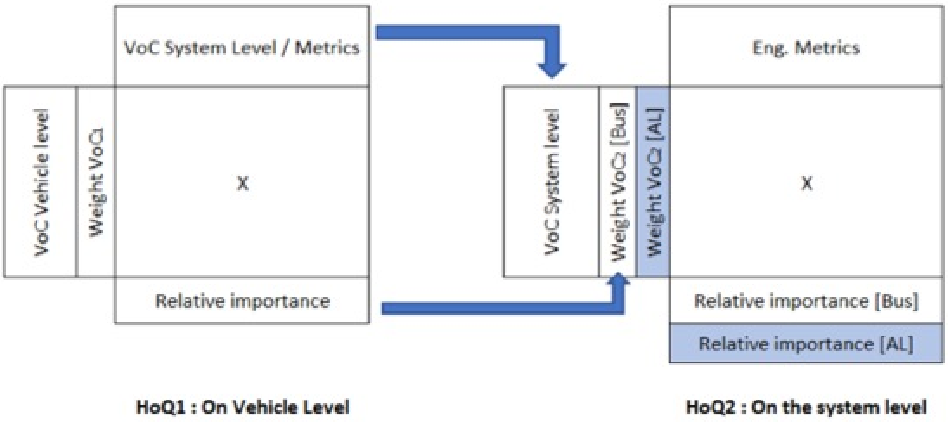


Figure 3.3: QFD process followed in this Master Thesis

3.3.1 House of Quality

The first phase in the Four-Phase Model the first matrix is the Quality matrix or House of Quality (HoQ). As shown in Figure 3.4, the HoQ is a systematic multiple step approach.

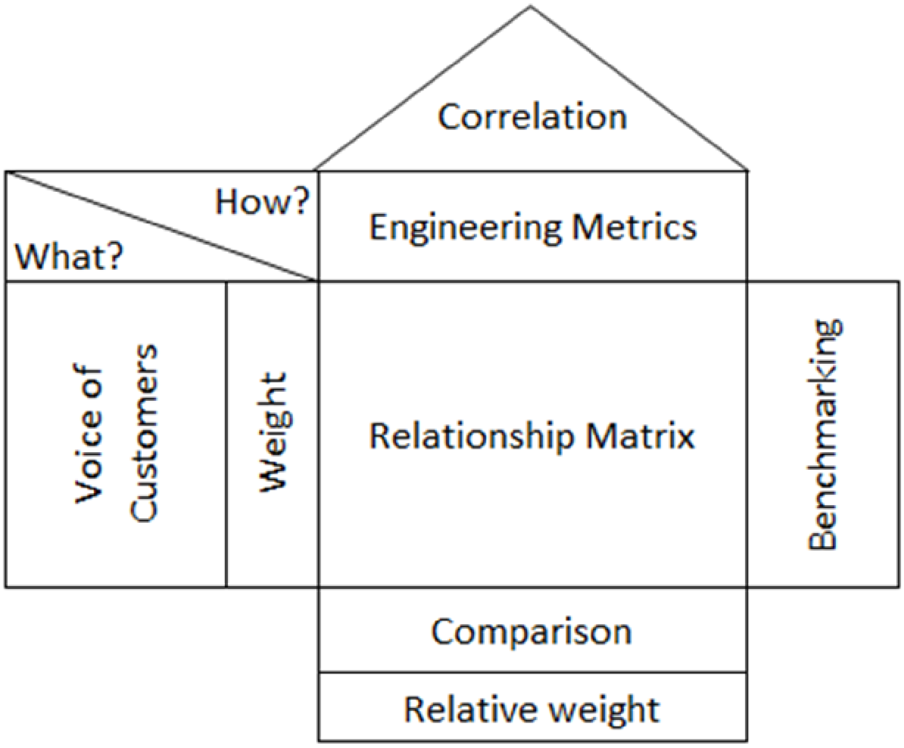


Figure 3.4: House of Quality (B.Bergman & B.Klefsjö, 2010)

The process starts by gathering the customer needs, or the "Whats" by conducting interviews or market surveys. In this stage, it is essential to understand the customer needs, *"what the customer buys and considers value is never a product. It is always utility, that is, what a product or service does for him"* Drucker (1974, p. 61). The second phase is to translate the need into Engineering metrics (EM) or the "How". An EM is a design objective that is measurable and can fulfil the requirements. The third step is to understand the relationship between customer needs and EM; an interrelationship matrix which based on a four-degree scale (no, weak, medium or strong correlation).

The fourth step in the HoQ process is to prioritise customer needs against each other; this is called Degree of Importance (DI) and should be a direct reflection of what the customer thinks is valuable. The fifth step is to make a competitor analysis to understand how the competitors' products or services perform against each customer need, which can also be a useful consideration in product development. The sixth phase is to make an engineering assessment of each EM and establish sharp targets for each and also assess the degree of difficulty to fulfil the metrics. The last step in the process is to understand the correlation between each EM, and a five-point scale judges the relationship by; Strong negative, Negative, None, Positive and Strong Positive relationship. With the help of this analysis, it is possible to distinguish which metrics counteract each other, which provides precise knowledge of potential trade-offs that are needed.

3.3.2 Voice of the Customer & Engineering Metrics

Initially, in the master thesis project, efforts were made to identify appropriate end-user data concerning the shutter system to base the VoC and the engineering metrics on. The challenge with the AS is that the majority of the end customer does not know that it exists, so there are very few unique end-user needs or complains referred to the shutter system itself. This approach implies the project to carry out a comprehensive data collection, and it was done principally by qualitative research methods. The data was gathered by two rounds of profound interviews with stakeholder, for instance, the different attribute leaders (technical experts in specific field aerodynamics, thermodynamics), concept engineers, business-, function- and product owner to the shutter system. This work resulted in over twelve individual interviews.

The first round of the interviews was designed according to semi-structured interviews with the primary objective to learn about the AS's impact on the specific attribute to get a holistic view of the system. The second round of interviews purpose was to gather and understand the VoC and EM of the separate attributes both at complete vehicle- and system level. Moreover, following the HoQ methodology also a gathering of benchmark cars set, VCC targets of engineering metrics and potential trends within the attributes area concerning the BEV. The last segment of the interview was to let the attribute leader provide proposals for new concepts and solutions, and this result was influential in the succeeding stages of the master thesis project.

3.3.3 Weight of the Voice of the Customer

A vital part of the QFD methodology and HoQ is to get the correct representation on how the customer ranks each Voice of Customer. This ranking was done through a five graded scale starting at one until five, where one relates to "not important" and five refers to "legal demands and significant importance." To get a reliable estimation without carrying out an end customer data gathering, the thesis project utilised the Appealing Design Business Owner (BO) to get a final judgement in the Product Planning matrix. The BO has the primary responsibility for representing the business perspectives, and she makes sure that the deliveries of the ART are aligned with the Business perspectives / customers needs. These estimations are essential due to the fact that the weights' relative importance permeate to the second matrix of part deployment and are affecting the results.

The QFD was customised to investigate if there are any deviations between the Business Owner and Attribute leaders' perspective. This approach revealed differences in opinion that are shown by the results in the part deployment matrix. The method used was to invite all the interviewed attribute leaders to a physical meeting. The first part of the meeting allowed the attribute leader to explain the attributes VoC and why the requirement was of importance. An anonymous vote then took place by an online survey with the same scale as for the business owner. If the group's results had too high variance, the group was asked to discuss and try to reach more consensus. After that, a new vote was performed to decrease variance within the group. Using these results it is possible to compare the Business Owners perspective with the Attribute Leaders and the difference created in the Part Deployment Matrix, as illustrated in Figure 3.3.

3.3.4 Interrelationship Voice of the Customer and Engineering Metrics

Having carried out the data acquisition of Voice of the Customer, the importance of each Customer need and EM; the last process of the HoQ is to determine the interrelationship connections between Voice of the Customer and EM. Since this step in the HoQ-process influences significantly the final result, it is fundamental to get the highest possible accuracy in this assessment. This evaluation was hence carried out in consultation with an experienced design engineer.

3.4 Concept Development

To develop the different concepts, several methods have been used to consider a scope as broad as possible, including innovation workshops, concept trees or morphological matrices. The concept generation ideas have been used in combination with concept selection methods to eliminate, screen and sort the different alternatives. The approach is summarised in Figure 3.5.

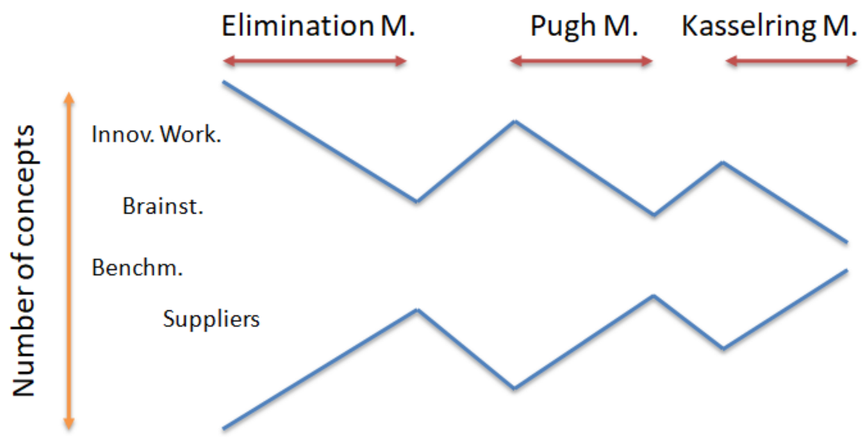


Figure 3.5: Scheme of Concept Generation process used in this project

3.4.1 Innovation Workshops

The innovation workshops aimed at gathering ideas outside of the box to make sure to investigate all the potential opportunities. Since studies show that diversity is critical for creativity (McLeod, P. L., Lobel, S. A. and Cox, T. H., May 1996), the various workshops gathered people from diverse backgrounds, occupations. It included people who work with shutters but also people who do not know that much about the current solutions.

The innovation workshops were divided into three main themes:
- Individual reflection (internal brainstorming (Paulus, P. B., & Dzindolet, M. T., 1993))
- Gathering the different ideas (gathering the ideas while staying silent)
- Exchanging about the different ideas (or group brainstorming (Paulus, P. B., & Dzindolet, M. T., 1993))

During all this process, it is important to ensure that the participants enter a "creative mode" then some mediating tools can be used:

- A "creative" powerpoint presenting the structure of the workshop;
- A specific question is used to guide the participants in their reflections
- creative material such as pens, highlighters, staples, tape to allow the participants to engage in getting more inspiration

To mitigate the risk of psychological inertia or group thinking (J. Kowalick, 21, Aug 1998), the group dynamics were considered of high importance during this stage. It was strongly emphasised that no idea was ridiculous.

3.4.2 Concept Generation

As explained by Ulrich & Eppinger (K. T. Ulrich & S.D.Eppinger, 2012), the concept generation process can be divided into five steps which are highlighted in Figure 3.6.

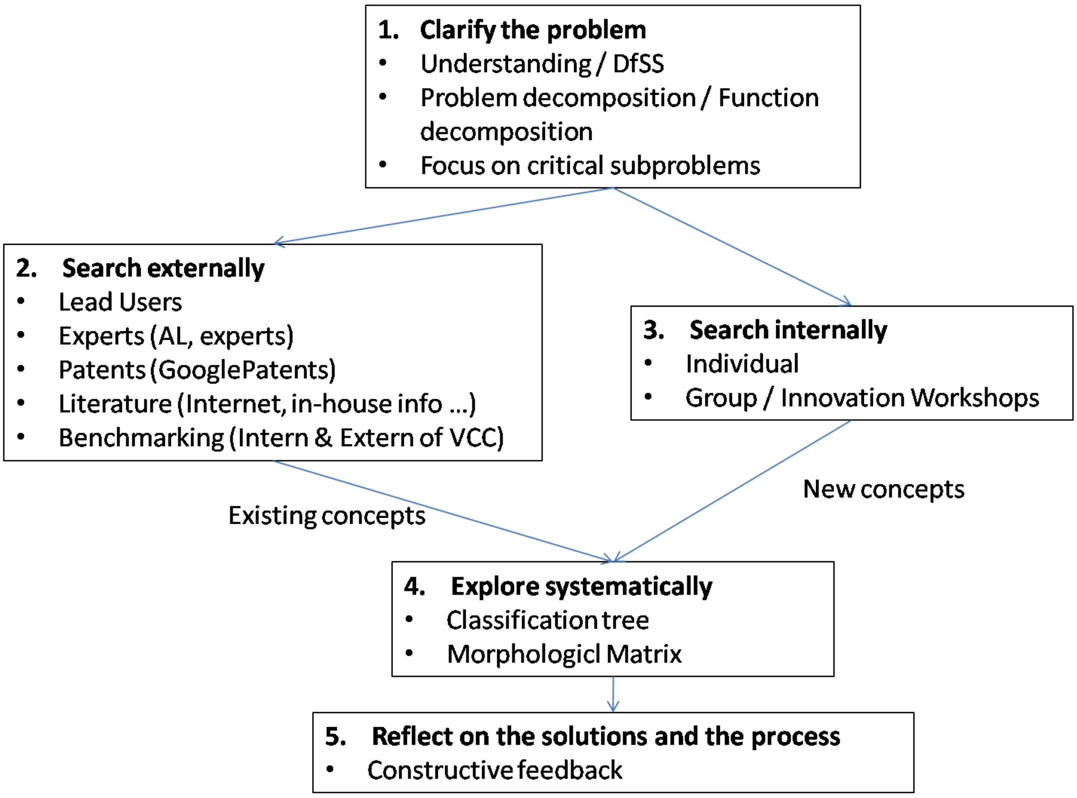


Figure 3.6: The five-step concept generation method adapted from Ulrich & Eppinger to the project (K. T. Ulrich & S.D.Eppinger, 2012)

As shown in the figure, it is critical to understand the problem in details in order to *Clarify the problem* before trying to solve it. A function-means tree can be used in order to decompose the complex problem/system into simple sub-problems and sub-functions.

When this is done, the effort can be focused on the critical sub-problems which have been previously identified. This can be done through *internal and external searches* (K. T. Ulrich & S.D.Eppinger, 2012) such as respectively Brainstorming, Interviews or Benchmarking.

These searches should be done *systematically* in order to investigate the whole solution spectrum. To do so, it is possible to use classification trees or a Morphological Matrix (K. T. Ulrich & S.D.Eppinger, 2012).
In this method, all the sub-functions of the part are detailed and the team tried to find as many alternatives as possible for each of these sub-problems. This enables the systematical combination of solution-chunks since it should be possible to assemble one alternative of each sub-function to create different concepts.

3.4.3 Elimination Matrix

The first method chosen for the concept selection is the Elimination Matrix which is a rough screening method by Pahl and Beitz (G. Pahl & W. Beitz, 2013).

All the generated concepts are judged against a list of criterion to do a first selection. Since the concept were conceptual at that time, the criterion should stay general but they can also be based on the requirements expressed on the system (e.g. the engineering metrics from HoQ).
To be able to pass the Elimination Matrix and be subject for further evaluation, the concepts had to fulfil all criterion from the specification, or the concept would be eliminated.

3.4.4 Pugh Matrix

The second evaluation method used in this project is the Pugh Matrix, also called concept screening according to Ulrich and Eppinger (K. T. Ulrich & S.D.Eppinger, 2012).

This matrix aimed at narrowing down the number of concepts and improving the remaining one based on the good aspects of the other ones. As shown in Figure 3.7, each concept is evaluated compared to a reference for every criteria and is marked by a "+" if it is better, "-" if it performs worst or "0" if both fulfil the criteria at the same level.

	Concepts				
	REF				
Criteria					
Sum of +					
Sum of 0					
Sum of -					
Net Score					

Figure 3.7: Pugh Matrix based on Pugh (Pugh, 1990)

The concepts can be ranked according to their net score (K. T. Ulrich & S.D.Eppinger, 2012). Moreover, the last concepts can be combined and they can help to improve the best ones since even the best concepts perform badly where another could have a better performance. The results are presented Section 6.3.2.

3.4.5 Kesselring Matrix

The third evaluation method used in this project is the Kesselring Matrix, also called concept scoring according to Ulrich and Eppinger (K. T. Ulrich & S.D.Eppinger, 2012).

In the Kesselring Matrix, presented in Figure 3.8, the criterion used were weighted and scaled to improve the accuracy of the evaluation of the concepts. A different scale (1 to 5) is created for each criteria to enable an objective scaling of the concepts. It is possible to add criteria on the resilience to the noises in order judge the concepts in their nominal but also real conditions.

	Relative Weight	Concepts			
Criteria					
Sum					
Rank					

Figure 3.8: Kasselring Matrix based on K. T. Ulrich & S.D.Eppinger (2012)

In the Kasselring Matrix, each concept is compared against the scale. The concepts can be ranked according to their net score (K. T. Ulrich & S.D.Eppinger, 2012). The method is used in Section 6.4.2.

4

Market, Societal and Technical Analysis

This section will present the results of the Market, societal and technical analysis gathered through the SWOT, the PESTEL, IP and benchmarking studies.

4.1 Analysis of the project context - SWOT

To be able to know where Volvo Cars is on the market today regarding the AS, conclusions were drawn from a SWOT-analysis, which can be seen in Appendix F. Meetings with stakeholders from VCC and searches from the internet have been used to gather more data about the company and its competitors.

VCC has been using AS for a long time even if most of them are Grille Shutters and some of the current cars (e.g. the project X) has used the same concept of shutters for the spoiler opening. This shows that VCC already has a (non-optimal) solution. On the other hand, a quick look at the variants on the markets (Section 4.4) highlights the fact that no major revolution has happened for years. Moreover the current concepts have been targeting the ICE vehicles whereas all the OEM are moving towards BEV (implying different requirements) which could be synonym of an opportunity for a different concept.

On the other hand, this stage of "early-innovators" goes along with higher risks and calls for a further investigation of the specifications.

As highlighted in the PESTEL (Section 4.2), this project is supported by the raising awareness of the environmental impact of human beings since governments around the world are planning to tighten laws concerning vehicle's emissions (German Association of the Automotive Industry (VDA), 2019) while the AS can (slightly) impact the drag coefficient C_dA.

By gathering all the experts at VCC, the project can benefit from the knowledge of experts in very different areas which is highly profitable in order to catch the trends. By doing so, this project will face very different points of view and will have to carefully balance them in order to achieve an optimal balance for VCC.

This project will also benefit from a synergy by working along another Advanced Engineering Project in the Cooling Department aiming at investigating smarter ways of controlling the AS.

4.2 Trends Analysis - PESTEL

The trends were examined through a PESTEL analysis and the full analysis can be found in Appendix G. Since cars are sold and used all over the world, the analysis was focused worldwide, but since this project targets only BEV, it focused more on that market and especially on their consequences on the AS.
Due to the similitude between the Political and Legislative Trends, it has been decided to merge them.

Political Trends	Economical Trends	Societal Trends	
Stricter environmental regulations in all the market	Cost Pressure. Try to share costs with other models & Co? Platform & modularization ?	Flexpool: Change of ownership principle. We rent a car according to the specific uses we have => all the cars are the same and used for very different uses 7/7 + bought by a professional.	BEV- Drive dista e.g. 50% of Volv
Less than 5% of potential buyers ultimately purchase an EV over an ICE model (~4% in the US, ~3% in Germany, and ~22% in Norway – due in part to government subsidies)	Cars sold in emerging countries. Which conditions? e.g. weather? or road quality?	Younger people using cars. More sensitive to noise.	AI raising. Could be used t
Bonus / Malus points. Right to drive certain days only if you are below emission limits	Under the current growth trajectory, EV producers could almost quadruple that achievement by 2020, moving 4.5 million units, around 5 percent of the overall global light-vehicle market. Pure electric vehicles (BEVs) currently make up 66 percent of the global EV market. BEV sales are growing faster than those of plug-in hybrid vehicles (PHEV). The Chinese market expanded by 72 percent over the previous year in 2017, solidifying China's leadership position in EV sales. The	China is leading the EV market https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/dynamics-in-the-global-electric-vehicle-market Based on emissions?	Digitalization

Figure 4.1: PESTEL Analysis of the Project - The sources are presented later

Political & Legislative
From a political view, environmental-friendly laws are enforced or are on the agenda of most of the governments or international organisations. For instance the EU will implement the most ambitious fleet target in the world in 2020 by limiting the emissions to 95g/Km in average for the fleet (German Association of the Automotive Industry (VDA), 2019). This trend may even accelerate by targeting around 60-70g CO2/Km in 2025 (Pichel, 2019). Since this regulation takes all the fleet into account, OEM are likely to compensate the emissions of their ICE by the BEV, boosting the selling targets of those.

By implementing its New Energy Vehicle (NEV) credits system, China also aims at reaching a balance between the importations of ICE and BEV (Laney Zhang - Librairy of American Congress, 9th May 2018) by fulfilling specific quotas.

The emissions of each car also impact the end-customers since they may have different levels of bonus when they purchase their cars. In general, subventions of governments are great incentives for end-customers to buy BEV (Stefan Knupfer, Russell Hensley, Patrick Hertzke, Patrick Schaufus, Nicholas Laverty & Nicolaas Kramer, Jan 2017).

Economic
The problems above are closely related to the economic aspects that have to be taken into consideration. As mentioned above, the price of a BEV is relatively higher than similar ICE vehicles at the purchase, being similar to an investment.

Therefore subventions from government are really effective to support the sells of BEV. This is partly why BEV tend to be more frequent in Germany, Denmark or Norway (Stefan Knupfer, Russell Hensley, Patrick Hertzke, Patrick Schaufus, Nicholas Laverty & Nicolaas Kramer, Jan 2017). Moreover this trend can help to forecast the main selling markets.

When it is compared to its cousin, the plug-in hybrid vehicles (PHEV), the BEV currently make up 66 percent of the global EV market. "Following the current growth trajectory, EV producers could almost quadruple that achievement by 2020, moving 4.5 million units, around 5 percent of the overall global light-vehicle market" and BEV are thought to keep the main part of this market. (Patrick Hertzke, Nicolai Müller, Stephanie Schenk, and Ting Wu, Mai 2018). And VCC is also part of this trend since it envisions that"50% of Volvo Cars' sales volume to be fully electric by 2025." (Volvo Car Corporation, 2019a).

It is important to highlight that "the Chinese market expanded by 72 percent over the previous year in 2017, solidifying China's leadership position in EV sales. The country now has a larger EV market—primarily BEV—than Europe and the United States combined." (Patrick Hertzke, Nicolai Müller, Stephanie Schenk, and Ting Wu, Mai 2018). This underlies that the gravity center of the customer needs may be shifted from the Western World to the Asian Market.

Last but not least, from the point of view of OEM, the profitability of BEV tends to be reduced compared to their other models (Yeon Baik and Knupfer, 2019). In the wake of this, OEM tend to be more than ever focused on cost reduction.

Social

From a social aspect, an important part is to make sure to understand who will be the end-customers of those cars. Being in the premium market, VCC tends to target families or professional. But the sells of the XC40 has showed that younger people can also be interested by VCC, raising the requirements on styling and the noise of components (Crona, 2018).

The number of platforms enabling customers to share their goods is raising (such as AirBnb or Uber). This highlights the premise of a radical change in how people react towards the goods they own. People do not want anymore to own goods which are not used regularly. This revolution has started in the automotive industry with for instance the creation of Lynk and Co or the increased use of Car Sharing services. This trend can significantly impact the AS since the same car could be used for very different needs (driving in the city or driving with a trailer on longer distance) during the same day. Consequently, this would blurry the boundaries between the different market segments.

Technological

As highlighted in numerous reports, an increasing number of surrounding products are now connected (Daniel Alsen and Shangkuan, 2017) and AS could benefit from this trend. This could optimise the control of AS according to the individual use of the car.

Today, the time needed to charge BEV is one of drawbacks compared to ICE vehicles and customers call for more efforts to reduce this time implying an increased energy transfer in a shorter time. In this case, the AS would become a bottleneck for the air-intake and then cooling needs. To be able to abide by the targets presented in the Political Section, the industry will be compelled to keep investing into energy efficient and reduced CO_2 emissions technologies.

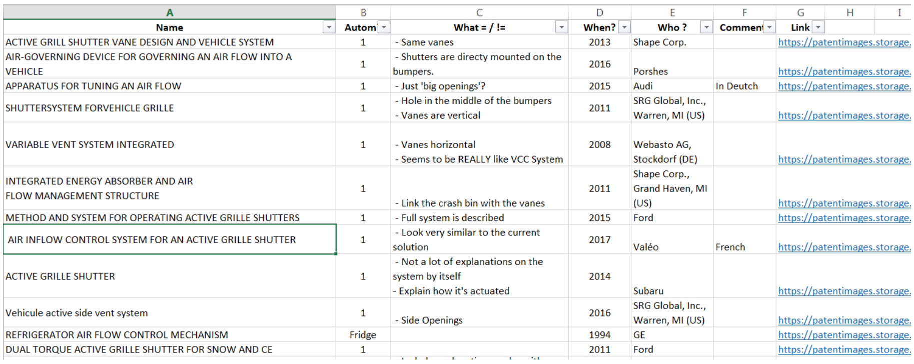
Environmental
As mentioned earlier, the environmental concern is taking a more consequent part in the government's agendas by implementing tightened energy consumption and emission laws.

Moreover, this can be achieved through the use of sustainable materials. VCC aims at using 25% of recycled polymers by 2025 (Volvo Car Corporation, 2019a) which means that around 2Kg of the system should be done in recycled polymers. The Life Cycle Analysis (LCA) in general is taking a more important place during the product development process. As stated in the VCC Guidelines, ethics matters from the sourcing of the raw materials till the daily use or even until the end of life of the AS (Volvo Car Corporation, 2019b).

Last but not least, the recent years or for instance the Spring 2018 in Sweden showed that the global warming affects the weather. In this specific case, it highlighted the fact that even in a Cold Market (such as Sweden), customers may face an ambient temperature higher than 30°C but they still expect AC to cool down the cab as quickly as in other conditions. Consequently, this also blurs the boundaries between each market segments.

4.3 Study of the main actors in the industry - IP study

The IP research has been done by using Google Patents and it covered different fields such as the automotive industry or others processes controlling fluids as highlighted in Figure 4.2.



A	B	C	D	E	F	G	H	I
Name	Autom	What = / !=	When?	Who ?	Comment	Link		
ACTIVE GRILL SHUTTER VANE DESIGN AND VEHICLE SYSTEM	1	- Same vanes	2013	Shape Corp.		https://patentimages.storage.		
AIR-GOVERNING DEVICE FOR GOVERNING AN AIR FLOW INTO A VEHICLE	1	- Shutters are directy mounted on the bumpers.	2016	Porshes		https://patentimages.storage.		
APPARATUS FOR TUNING AN AIR FLOW	1	- Just 'big openings'?	2015	Audi	In Deutch	https://patentimages.storage.		
SHUTTERSYSTEM FORVEHICLE GRILLE	1	- Hole in the middle of the bumpers - Vanes are vertical	2011	SRG Global, Inc., Warren, MI (US)		https://patentimages.storage.		
VARIABLE VENT SYSTEM INTEGRATED	1	- Vanes horizontal - Seems to be REALLY like VCC System	2008	Webasto AG, Stockdorf (DE)		https://patentimages.storage.		
INTEGRATED ENERGY ABSORBER AND AIR FLOW MANAGEMENT STRUCTURE	1	- Link the crash bin with the vanes	2011	Shape Corp., Grand Haven, MI (US)		https://patentimages.storage.		
METHOD AND SYSTEM FOR OPERATING ACTIVE GRILLE SHUTTERS	1	- Full system is described	2015	Ford		https://patentimages.storage.		
AIR INFLOW CONTROL SYSTEM FOR AN ACTIVE GRILLE SHUTTER	1	- Look very similar to the current solution	2017	Valéo	French	https://patentimages.storage.		
ACTIVE GRILLE SHUTTER	1	- Not a lot of explanations on the system by itself - Explain how it's actuated	2014	Subaru		https://patentimages.storage.		
Vehicule active side vent system	1	- Side Openings	2016	SRG Global, Inc., Warren, MI (US)		https://patentimages.storage.		
REFRIGERATOR AIR FLOW CONTROL MECHANISM	Fridge		1994	GE		https://patentimages.storage.		
DUAL TORQUE ACTIVE GRILLE SHUTTER FOR SNOW AND CE	1		2011	Ford		https://patentimages.storage.		

Figure 4.2: Extract from the Patent Research

In general, the solutions provided by the different OEM are similar to each other as showed in Figure 4.3 & 4.4:

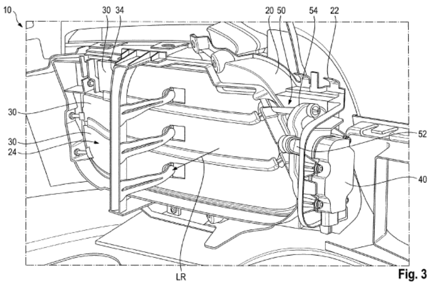


Figure 4.3: Extract from a patent of AS for the Porsche 911 (Dimitar Danev, 2015)

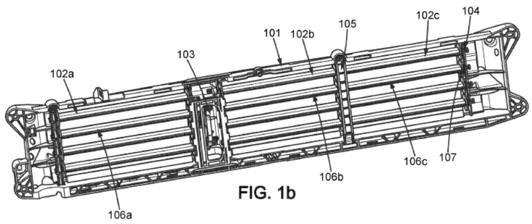


Figure 4.4: Extract from a patent of AS from Valéo (HERLEM, 2017)

On the other hand, an increasing number of patents have been filled on the AS control in order to make it more proactive and tailored to each driver or vehicle.

Furthermore the IP study helps to understand the current trends of the market. As shown by Figure 4.5, Google Patents also highlights the companies which apply for the more patents, implying the companies which invest the more in the technologies. If those companies are suppliers (and not OEM) they could be investigated or contacted to see in depth if their products could fit VCC.

If those players belong to other fields, it could be also relevant to investigate if those technologies could be adapted and patented for the automotive industry.

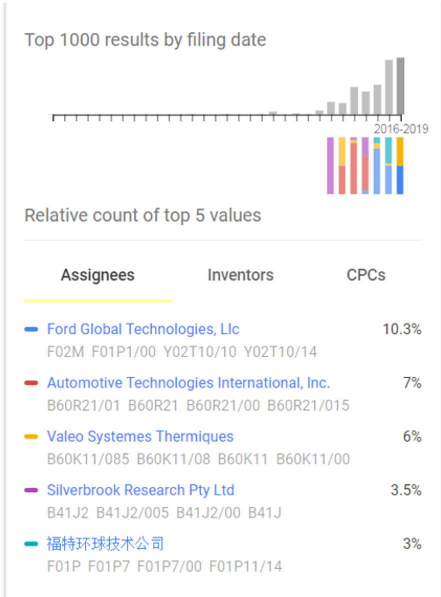


Figure 4.5: Top 10 of the companies in term of patent worldwide - Source : Google Patents

4.4 Technological Analysis of the current products - Benchmarking

Benchmarking is often used in the business environment and is the foundation of a tool whose goal is to improve products and processes, to increase profitability within an organization by implementing best practices. There are several different approaches to carry out a benchmarking, for example through key performance indicators, competitors, doing an internal or external study. According to (Bogetoft, 2012), this one of the most used tool when organizations look for improvements. Bogetoft (2012) proposes two central steps for all kinds of benchmarking which are:

- The first step is to choose a function, product or service where one can identify a gap in its performance, then select the relevant key performance metrics to be able to do a focus benchmark around.
- When the data is collected, it should be analyzed to identify benefits, improvements and therefore bring in new ideas (Bogetoft, 2012).

During the project, the benchmark was used as a central element for the concept generation and to strengthen internal understanding of the product. Since BEV are a relatively new phenomenon on the automotive market and to think outside the framework, the benchmark process was divided into three phases.

The first step part was to review the shutter function from a broad perspective. This stage was done by examining how external industries (all industries excluding the automotive sector) solve the task. The second step and focus area was to make a competitor analysis for BEV. The last part was to do an internal benchmark within

VCC to see if there are combined solutions that could simplify the function.

4.4.1 Benchmarking outside the automotive-industry

To understand the function of the AS *"control the air flow"* outside the established frameworks for the automotive industry and to gain knowledge of how other industries solved the function, an external benchmark was first performed.

An industry that was carefully scrutinised was the process industry where, for example, different types of valves were examined to understand how they control the air-, and liquid flow. The result of feasible solutions were gate-, ball- and butterfly valves.

Further benchmark was carried out on smart materials since one or more properties changed significantly in a controlled manner by external influences, for example, shape memory alloys and piezoelectric crystals could be integrated into the shutter system. This benchmark was used in the concept generation phase of the project where the feasibility and implementation possibilities of the methods were assessed.

4.4.2 Benchmarking automotive industry

As described in the introduction of the report, the shutter system has existed in different shapes and with different functionality in the automotive industry for decades. During its first concepts, the construction was simple with a drapery that the driver manually controlled to increase the temperature in the engine room.

The latest eras of the shutter system's began when the OEM started optimizing the vehicles. This included increasing efficiency by reducing the aerodynamic drag, improving cooling performance, noise reduction, improving cold start, and heat retention.

The automotive industry benchmark was explicitly focused on one area, BEV. Besides, a benchmarking study has also been done on the HEV and ICE vehicles, but only the solutions which differ from conventional shutter systems with hidden horizontally mounted vanes are presented. The tool that is primarily used to provide out these studies was "A2Mac1 Automotive Benchmarking", which is an online website where dismantled vehicles parts are presented at a component level.

- **Tesla Model 3 2018 (BEV, North American market):** This car model is using only a hidden spoiler shutter. The two vanes are horizontally mounted in two arrays, with the flap mechanism in the center of the vane. This shutter is shown in Figure 4.6. In this model, the activator is located in the middle support of the shutter. Worth mentioning is that Tesla has used a tilted cooling pack.

Figure 4.6: Tesla Model 3, spoiler shutter

- **Tesla Model-X P90D 2016 (BEV, North American market):** There is a hidden spoiler shutter in the model. The two vanes are horizontally mounted in two arrays with the activator located middle support. This model also utilises a tilted cooling pack.
- **Jaguar I-Pace EV400 2019 (BEV, EU market):** In this model there is a hidden active spoiler shutter, but also a small passive opening in the grille. The spoiler shutter vanes are three horizontally mounted in two arrays with activator located middle support. The flap mechanism that drives the vanes is attached in the center support.
- **BMW i3 Range Extender Urban Life 2014 (BEV, EU & North American market):** This model i3 has a spoiler opening but there is not any shutters, just an air guide (a passive solution).
- **Volkswagen Golf VII e-Golf 2014 (BEV, EU-market:** This model of e-Golf has a spoiler opening but there is not any shutters, just only an air guide (a passive solution).
- **Volkswagen Golf VII e-Golf 2018 (BEV, North American market):** This model uses a hidden spoiler opening and has a spoiler shutter system installed. The system is a conventional solution with two arrays of four vanes each. The motor support and flap mechanism are integrated into the central support. What can be added further is that the shutters have an integrated exterior temperature sensor in the frame of the system, further investigations need to be done in order to understand the function of the sensor.
- **Audi e-tron 55 Quattro Edition One 2019 (BEV, EU-market):** When the project executed the benchmark process, A2Mac1 had this car "in progress" which means that only a limited numbers of pictures were available. But the temporary conclusions that can be made is that this model applies both grille- and spoiler shutters hidden behind the A-Surface.
  Furthermore, the grille shutters have been distinguished from the conventional design since the central support of the frame has been removed and replaced with two thin structural support in the frame. This solution then implies longer vanes (735 mm) and another flap mechanism. This solution should be further investigated with physical testing what the aero- and thermodynamic consequences are.
- **Hyundai Kona electric Executive 2018 (BEV, EU-market):** this model

uses a hidden spoiler opening and has a spoiler shutter system installed. The system is a conventional solution with two arrays of two vanes each. The motor support and flap mechanism are not integrated within the central support, with the consequence that the centre support becomes thinner.

- **BMW 5 Series 530e iPerformance 2017 (HEV, EU-market):** The reason why this vehicle is of interest is that the grille shutter differs from the conventional variant. In this case, the system integrates into the grille and the A-Surface with vertical vanes with advanced mechanical rotation mechanism. Theoretically, this solution should be beneficial from an aerodynamic perspective, which should be investigated in physical wind tunnel testing.
- **Porsche 911, 992-generation 2020 (ICE, Not investigated):** This car has not been benchmarked by A2mac1 yet but has been presented by Porsche external communication. What is interesting about this vehicle is that two wheelhouse shutters are used, these are also integrated into the bumper skin and are visible to the customer. This vehicle is the first to be found where the spoiler shutter is integrated with the A-Surface.

General benchmarking of competitors ICE- and HEV vehicles confirms that the majority of the competitors in the premium car segment is using shutters. But far from everyone in the industry are adopting the shutter systems, especially the low-price segment. The common solution is hidden shutter behind the A-Surface (bumper skin), very similar to Volvo's solutions 2.3. This system type was described in detail in chapter 2 but is based on two rows of two - four horizontal mounted vanes, supported in the middle of the frame.

Nevertheless, there are some variations, learnings and unique solutions on the market. The most forward-looking concepts among those which have been benchmarked are the BMW 5-series and Porsche 911 which have an integrated shutter system within the A-Surface. What is interesting with this type of idea is that the shutter system becomes visible to the customer, and the function becomes a design characteristic. Furthermore, there are aerodynamic advantages of placing the shutter in the A-Surface, as it theoretically reduces drag. The prominent arguments opposite for this type of solution are the cost perspective of the system but also a more significant risk of external influences such as contamination or stone shipping.

Regarding shutter systems for BEV, most of the competitors have used the same type of solution as for ICE and HEV but with the difference that only the spoiler is utilized for BEV. However, some lessons should be considered and further examined. First, the Tesla solution of the inclined cooling package should be evaluated physically and further benchmarked. Regarding the shutter system, optimisation should be made. Primarily to remove or minimise the central support so that utilising open area is optimised.

4.4.3 Benchamrking within Volvo

In the closing phase of the benchmarking process, internal benchmarking at Volvo was performed. This step aimed at investigating if there were other components in the vehicle which solve similar functions or a sub function of the shutter system. These meetings were with colleagues from other departments like closures- or sealing system. By meeting these people, the general knowledge of different components in the car increased.

The essential learnings was how other department solved similar issues. For instance, as explained earlier in the project ice-locking of the shutter system is a problem. So a meeting with responsible for the locking mechanism in the doors took place to get inspiration on how the departments had solved these issues.

4.5 Discussion

This part provides an short discussion of the results presented earlier regarding the market, societal and technical study.

4.5.1 Market and Societal analysis

The results from Market and Societal analysis show that the vehicle industry is in a transformation towards more fully electrical vehicles (BEV). This transition is partly linked to the willingness to develop a more sustainable mobility option.

Despite this, we should not underestimate the environmental costs needed to product the battery and the vehicle in general. The environmental footprint is also very dependant on the source of the energy (e.g. coal, nuclear or hydraulic). Other new options may appear in the future such as Hydrogen Vehicles, or even alternative ways to "own" a car with for instance the creation of the sharing-car services.

An additional driving force is through the authorities' requirements and legislation for emission reductions, therefore the cost will significantly increase for vehicle manufacturers which do not comply with the guidelines. This aspect is very much dependent on the political views of each country but there is a clear tendency for the citizens who want to change things as we saw the students strikes lead by Greta Thunberg in Spring 2019. European Elections will also draw a clear path on the next steps.
Regarding Volvo, there is a communicated strategy that in 2025 should 50% of the sales volume to be fully electric.

However, there are comprehensive challenges with this transformation such as the range of the BEV (which is the current order-winner), the time needed to fast-charge, and particularly the cost constraint. These three categories the shutter influence. It can easily see that those parameters are the typical ICE parameters. This means that the customers have not changed their ways of seeing a car yet, since having a BEV and ICE does not mean "owning" them in the same way. Changing this mindset may take a significant time.

Last but not least, the relatively small number of suppliers as well as the research of optimization may partly explain how there is such an alignment in the automotive industry where the majority use the same type of solutions and design, where the risk areas shutter system are limited.

4.5.2 Technical analysis

The benchmarking was quite useful and the file was used many times throughout the process for information searches on different products. The file was also used as a reference for the Design Engineers. Also, by benchmarking and looking at current products already existing on the market, it could be that the master thesis group and concepts were highly influenced by existing products.

This could therefore have affected the result in both a positive or a negative way. If the project group had not looked at any existing alternatives a completely different solution may have arisen, but there would also have been a risk of reworking or reinventing products that already existed.

And despite the fact that the benchmarking process was iterative, new information was collected each time since we were never looking for the same kind of information at each iteration. This means that (even if this iterations could not have been avoided,) the project could have benefited from having more systematical researches from the initial steps.

Regarding the IP studies, they gave limited result due to the complexity of the patent formulations. It was particularly hard to understand the limits of each of them to draw the FO-space. However, the patent investigation indicated which supplier are the most active regarding development of shutter systems. This result encouraged contacting these suppliers to discuss their views regarding the shutter-technology direction.

In the case of the shutter system, this is easy to see that the vast majority of the OEM's solutions are relatively similar on a concept level. But there are differences at the system level which should not be underestimated (such as 2K vanes, length of the vanes, vanes' linkage) since they affect the final performance and cost of the system a lot.

In retrospect, the project would have benefited from "purchasing" the competitor products for testing to create a better understanding of their limitations or advantages. This would have made a difference compared to solely investigating them online or viewing them through benchmarking tools. On the other hand, it would have also been complex to order competitor's parts. It is also essential to highlight

the cost of those parts which can reach 1000SEK / 100€ for certain OEM, and this would have reached a significant cost for the project and department.
Moreover, the project has provided a set of competitors benchmark so that the next phase would be physical testing of the most engaging models.

Finally, the benchmarking outside the existing shutter system framework was very rewarding. One of the interesting results is the development of smart materials, which are material whose properties can change due to application of specific influences (e.g. current or strength). Furthermore, the internal benchmarking performed within Volvo was very informative and increased the group's knowledge of other components in the vehicle. This method is also an essential part of internal product development, so smart solutions are applied if possible in several places.

4.6 Conclusion

The conclusion of this section is that the current market trend is going toward more electrified and cleaner vehicles, and the OEMs which do not follow this may be penalised by fines. The current most desired vehicle features are the range and the charging-time.

Regarding the shutter system and benchmarking, most OEM are solving the function with similar solutions to Volvo's and there are minor differences between ICE and BEV shutter solution. The forefront of the OEMs have integrated the AS to the A-Surface, but most of them are still hiding it. However, there are improvements Volvo can make to optimize the system more than it is today to increase the performance.

5

Translation of the customer needs into Eng. Metrics using the House of Quality

In order to establish the list of requirements to develop a new concept of active shutters for Battery Electrical Vehicles, the QFD has been used to make sure to relate the requirements to the customer needs.

For this section, it is significant to highlight that the House of Quality (HoQ) targeted the Design but also the Control of the AS in order to support a complimentary Advanced Engineering project carried out in the Cooling Department.

Furthermore, the project did not have any specific car project in intention, but preferably a conceptual concept which could be implemented in the following vehicle program.

5.1 Identify VoC

As highlighted in Section 3.3.2, the AS has the particularity of been hidden from the end customers.

The Attribute Leaders (AL) have the responsibility of understanding and translating the needs of the customers in their areas and based on that. The different attributes can establish requirements on the complete vehicle or sub-systems (such as the AS). Thus over twenty individual meetings have been organised with the main Attribute Leaders or some experts such as:

- Aerodynamics
- Thermodynamics
- Climate
- Perceived Quality
- Styling
- Purchasing
- Manufacturing Engineers
- Concept Engineers
- Cooling (the department owning the function of the AS)

- Contamination
- Energy Efficiency

During those meetings, twelve House of Quality has been initiated as presented in Figure 5.1 in order to accumulate the Voice of Customers (VoC) in each of the Attribute Areas (1), the EM (2) and their targets (3), the trends, the targets (for VCC and Polestar) as well as a quick benchmarking of selected premium OEM (4).

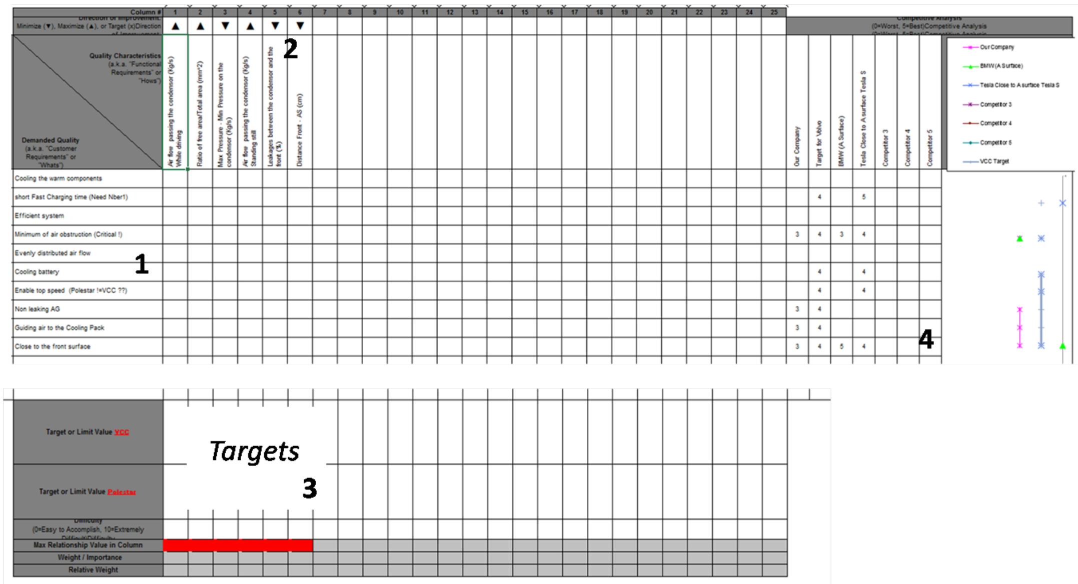


Figure 5.1: Extract from the HoQ filled with the AL from thermodynamics during the first individual meeting

Those individual meetings lasted one hour and included a short presentation of the QFD process, a presentation of the HoQ, a discussion regarding the VoC as well as a brief brainstorming. As soon as those VoC and Engineering Metrics (EM) have been gathered, they have been divided amongst different scales: vehicle- and part levels.

- The **Vehicle level** gathers all the requirements which are expressed on the full vehicle. The corresponding Engineering Metrics can only be tested on a fully assembled vehicle.
- the **System level** gathers all the requirements that only target the system. Thus the engineering metrics from this level can be directly tested on the system, and they do not require a full vehicle.

At the end of this phase, there were 22 VoC expressed on the vehicle level, 35 on the system level and respectively 17 and 23 EM on the vehicle and System level.

The previous numbers were judged as being too consequent for the project. Thus it was decided to select until fifteen VoC as well as EM from each level. To do so, the data had been gathered by clusters, and the collection has been done, making sure that all of them were represented.

5.2 Weighting the VoC at Vehicle Level

As highlighted in Section 3.3.3, the next step was to weight the different VoC previously picked using the scale presented in the Table 5.1 :

Value	Meaning
5	Legal
4	VCC is THE leader
3	VCC is among the leaders
2	VCC is competitive
1	VCC is Under competition

Table 5.1: Scale used to characterise the VoC established on the Vehicle Level (Ariño, 2019)

Following a discussion with the Business Owner responsible for the part, the VoC has been assigned priorities which cannot be shown in this Report for confidential concerns.

5.3 Weighting the VoC at System level

As mentioned in Section 3.3.3, it was decided to compare the results between the business- and AL sides. In order to accomplish that, the VoC on the System Level was weighted by the stakeholders during a collective meeting of two hours.

After prior personal preparation and with the support of the Quality Hardware Team, all the AL and other stakeholders who helped to gather the VoC have been invited for this meeting. All AL had been provided the list of selected VoC to check that they agreed with the selection done by the team. To break the boundaries of each Attribute Area silo, the meeting started by presenting all the customer needs to make sure that all the stakeholders present to the meeting could understand all of them.

After this short introduction, each VoC has been taken one by one and has been weighted by the stakeholders. In order to provide an anonymous but also direct answer, it was decided to use a Microsoft Survey as a mediating tool for the vote (an extract is presented in Figure 5.2).

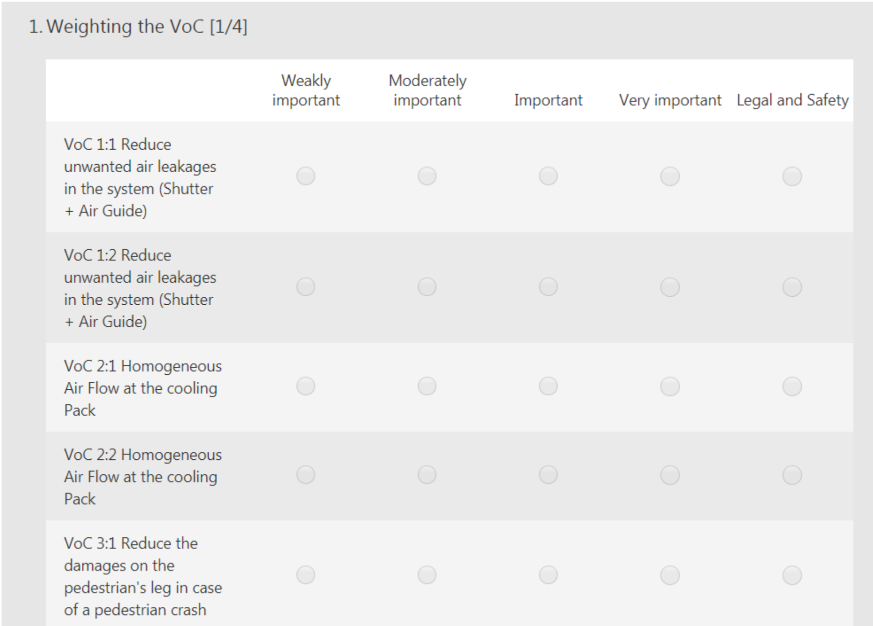


Figure 5.2: Extract from the Survey gathering the VoC from the respondents

1. For each VoC, the stakeholders started to vote before any discussion in order to compare their views before and after discussion. For this first vote, they used the lines "VoCx.1" (where X is the number of the VOC - $x = [1...20]$). Their anonymous answers could directly be visible in Figure 5.3.The scale was divided into five levels : "Weakly Important", "Moderately Important", "Important", "Very Important" and "Legal & Safety".

2. If the dispersion was judged as too high, a discussion of around three to four minutes was started to support the stakeholders to understand the point of view of each other and particularly from the author of the VoC.

3. In the case of the discussion, the stakeholders voted a second time in order to produce a definitive answer following the discussion.

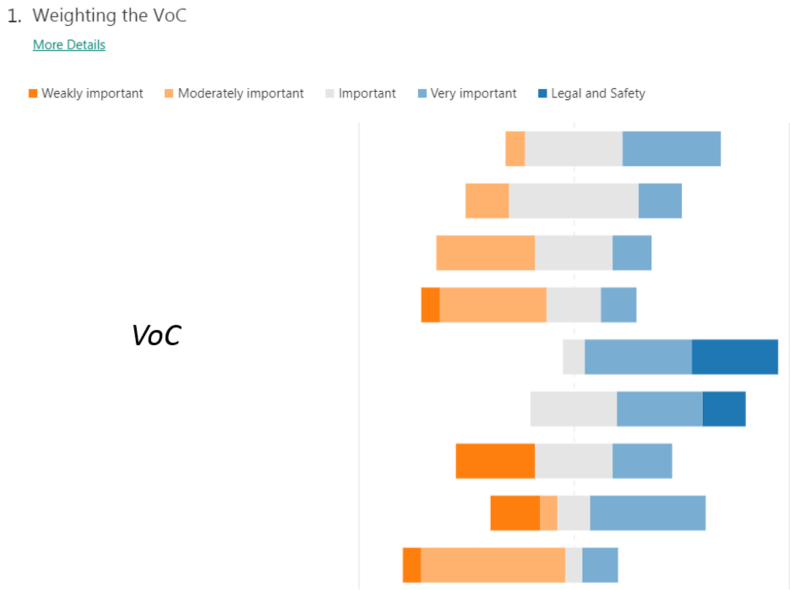
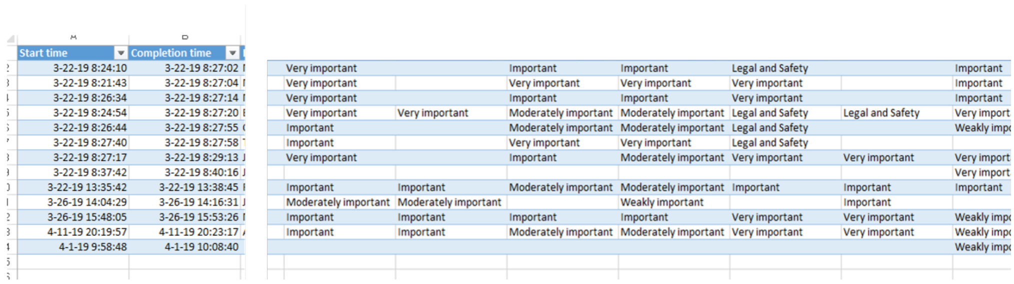


Figure 5.3: Extract of the direct-answers of the stakeholders to the Survey

After this meeting, the project team extracted the Excel file gathering all the answers (and attribute areas) of the respondents (as can be seen in Figure 5.4) to proceed to some evaluation and further detailed analysis.



Start time	Completion time							
3-22-19 8:24:10	3-22-19 8:27:02	Very important		Important	Important	Legal and Safety		Important
3-22-19 8:21:43	3-22-19 8:27:04	Very important		Very important	Very important	Very important		Important
3-22-19 8:26:34	3-22-19 8:27:14	Very important		Important	Important	Very important		Important
3-22-19 8:24:54	3-22-19 8:27:20	Very important	Very important	Moderately important	Moderately important	Legal and Safety	Legal and Safety	Very import
3-22-19 8:26:44	3-22-19 8:27:55	Important		Moderately important	Moderately important	Legal and Safety		Weakly impo
3-22-19 8:27:40	3-22-19 8:27:58	Important		Very important	Very important	Legal and Safety		
3-22-19 8:27:17	3-22-19 8:29:13	Very important		Important	Moderately important	Very important	Very important	Very import
3-22-19 8:37:42	3-22-19 8:40:16							Very import
3-22-19 13:35:42	3-22-19 13:38:45	Important	Important	Moderately important	Moderately important	Important	Important	Important
3-26-19 14:04:29	3-26-19 14:16:31	Moderately important	Moderately important		Weakly important		Important	
3-26-19 15:48:05	3-26-19 15:53:26	Important	Important	Important	Important	Very important	Very important	Weakly impo
4-11-19 20:19:57	4-11-19 20:23:17	Important	Important	Moderately important	Moderately important	Very important	Very important	Weakly impo
4-1-19 9:58:48	4-1-19 10:08:40							Weakly impo

Figure 5.4: Extract from the Excel file gathering the answers from the respondents

The answers provided by the Excel file were used in order to calculate the average and variance of the answers to weight the different VoC with a value from 1 to 5.

5.4 Correlation between the metrics

The following step was the investigation of the correlations between the different Engineering Metrics and including how influential it is, following Table 5.2:

This scale was used to characterise the correlations between each Engineering Metrics as seen in Figure 5.5.

++	Strong Positive Correlation
+	Positive Correlation
	No Correlation
-	Negative Correlation
∇	Strong Negative Correlation

Table 5.2: Scale for the Correlation between the Engineering Metrics

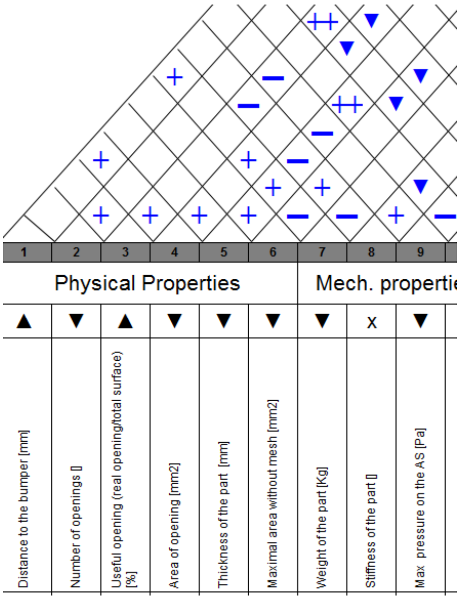


Figure 5.5: Extract from the HoQ - Zoom on the correlations between EM

5.5 Interactions between the VoC and metrics

As mentioned in Section 3.3.4, the relationships between the EM and VoC have been characterised according to the scale illustrated in the following table 5.3:

Symbol	**Value**
Θ	Strong Relationship
O	Moderate Relationship
△	Weak Relationship
	No relationship

Table 5.3: Scale used to characterise the relationships between the VoC and EM.

This scale has been used for all the VoC and EM, as shown in the following Figure 5.6, and the values have been checked with experienced Design Engineers from the

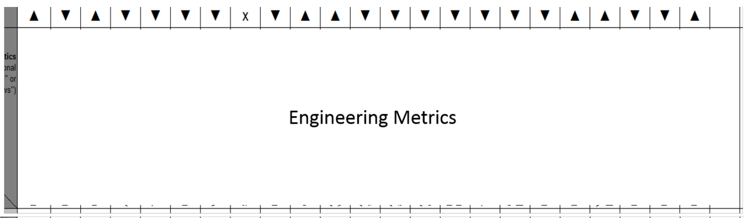
Volvo development team.

Quality Characteristics (a.k.a. "Functional Requirements" or "Hows") / Demanded Quality (a.k.a. "Customer Requirements" or "Whats")	Reduce unwanted air leakages in the system (Shutter + Air Guide)	Homogeneous Air Flow at the cooling Pack	Keep the Shutter open when braking at high speed	Sealed when the shutter is closed	Reduce weight	Increase air entry (ex. Min of air obstruction)	Protect the cooling pack from gravels	Resist water and air pressure (high speed or water pressure)	Close as possible to the bumper skin	Reactive to fast cooling needs	Controllable in multiple steps
The car has a premium look							▲		⊙		
Not seen at the 1st look by the customer						○			○		
Reduce over-hang of the front (distance wheelhouse -> front)							▲		⊙		
Pass the Pedestrian safety tests									▲		
Increased Design Freedom						▲			⊙		
Climate comfort (cupe')	⊙	⊙		⊙		⊙	○		▲	⊙	⊙
Increase the Range (energy efficient)	⊙	⊙		⊙	○	○			○	○	⊙
Keep stability while braking			⊙								▲
Be able to drive in all customer environment	▲		▲	▲		▲	⊙	⊙		○	○

Figure 5.6: Extract from the HoQ - Relationships between VoC and EM

5.6 Final Results

All the previous steps summarised in Figure 3.3 enabled the team to measure the relative importance of respectively of the EM expressed on the system level from a Business and AL perspective as highlighted in Figure 5.7.



(0=Easy to Accomplish, 10=Extremely Difficult)																								
Max Relationship Value in Column	9	3	9	9	9	9	9	9	9	9	3	3	9	9	9	9	9	9	9		9	9	9	
Weight / Importance AL	326,5	94,0	164,9	259,1	68,0	95,1	59,6	261,5	77,0	130,3	35,9	36,5	170,1	87,6	66,0	94,8	31,2	160,4	161,4		202,1	89,7	70,6	
Relative Weight AL	11,9	3,4	6,0	9,4	2,5	3,5	2,2	9,5	2,8	4,8	1,3	1,3	6,2	3,2	2,4	3,5	1,1	5,8	5,9		7,4	3,3	2,6	
Weight / Importance Business	372,4	90,4	141,7	190,2	68,0	193,1	36,0	220,7	49,7	139,2	37,5	51,4	133,3	76,9	87,9	93,7	20,3	224,5	234,8		209,8	117,8	57,8	
Relative Weight Business	13,1	3,2	5,0	6,7	2,4	6,8	1,3	7,8	1,7	4,9	1,3	1,8	4,7	2,7	3,1	3,3	0,7	7,9	8,2		7,4	4,1	2,0	
Difference Business / AL	12,3%	4,0%	16,4%	36,2%	0,0%	50,7%	65,2%	18,5%	54,9%	6,4%	4,5%	29,0%	27,6%	13,9%	24,9%	1,1%	53,5%	28,5%	31,3%		3,6%	23,9%	22,1%	

Figure 5.7: Extract from the HoQ highlighting the differences between the AL and Business point of view

On the other hand, the requirements on the system are listed (in random order) in the following Table 5.4 (the values have been removed from the Table for confidential concerns):

Relative Importance	**Requirements**
	Compressed length of AS [mmx]
	Number of openings []
	Useful opening (real opening/total surface) [%]
	Area of opening [mm2]
	Thickness of the part [mm]
	Maximal area without mesh [mm2]
	Weight of the part [Kg]
	Stiffness of the part []
	Max pressure on the AS [Pa]
	Distance to the bumper [mm]
	Airflow passing the condenser while driving with an OPEN AS [Kg/s]
	Airflow passing the condenser while standing still with an OPEN AS [Kg/s]
	Airflow passing the condenser while driving and with an CLOSED AS [Kg/s]
	Air flow leakages between the front and the cooling pack [%]
	Pressure difference on the cooling pack [Pa or Kg/s]
	Time needed to open/close the shutter [t]
	Change of the opening surface when braking [mm2]
	Number and Severity of appearance issues
	Fit to Volvo design
	Drag Coefficient Cd*a
	Ice locking Errors (%)
	DfA KPI []

Table 5.4: Final requirements on the System Level

5.7 Discussion and Conclusion

This section comes back on the results presented in the previous section to discuss them in order to draw an intermediate conclusion regarding this first milestone. Last but not least, the HoQ enabled cross-functional exchanges to fill its different rooms.

5.7.1 Identify VoC

As mentioned in Section 5.1, the initial meetings with the AL aimed at presenting the tool and gathering the VoC addressed on their Attribute Areas and those meetings have been carried out individually for each of them. Thus this lacked efficiency, having to repeat the same explanations several times, but this choice was mainly made for the AL to have less impact possible on their schedule.
Those individual appointments enabled us to learn about each area and to develop the knowledge necessary to accomplish with those VoC. Furthermore, each AL, as an expert of his field, tends to think of solutions and 'automatic' replies tend to be answered automatically when inquired them. Therefore the "5-Whys-method" were used to investigate their answers and to find their root-cause to link them to the business needs.

Our second step in identifying the VoC was to select an appropriate number of them. To do so, we can recognise that our experience and knowledge was not detailed enough at that time to differentiate certain VoC and to avoid some confusions. As we discovered later, it is critical to stay fair to all AL by selecting an equal and fair number of VoC within all the Attribute Area. In this case, we can comprehend that our high number of styling requirements have unbalanced the results, giving further importance to styling Engineering Metrics.

5.7.2 Weighting VoC at Vehicle Level

As explained in Section 5.2, the Business Owner helped to make the team has highly appreciated the relationship between the Business and the system, and this link since it gave strength to the end-results. As aimed by the QFD, the designers can relate their decisions and design parameters to real business considerations.

5.7.3 Weighting VoC at system level

In theory, in order to weight the different Voices of Customers based on the DfSS theory, we need to distinguish each VoC to each other to be able to limit the effect of subjectivity. This step should have been done, including all the stakeholders.

In our case, this would have mean gathering the AL during around eight hours to answer together 20^{20} questions (Raharjo, 2019). This fact is why the method used in our project is a compromise between the time needed from the AL and the subjectivity of their answers.

First, the scales have been used to help the stakeholders to understand the value of each step and to make sure that all of them had the same amount for it. Consequently, the phrasing of those scales should be able to create an objective scale independent of everyone's mental models. Despite our researches and reflections, we did not manage to create such a scale, and that created some confusion during the meeting with the AL.

As explained in Section 5.3, in the wake of our 12 individual meetings, we gathered more than 40 different VoC. As mentioned earlier, they have been assembled by clusters to select only 15 VoC out of them by merging some of those needs. This process affected the formulation of the VoC, and the meeting with all the AL highlighted to what extent this formulation was critical to define precisely each need. Thus we had to redefine one VoC during the meeting to re-align it with what the AL had in mind and avoid confusion. Having this in mind, we should have spent further time and checked with the AL beforehand the formulation of each VoC.

To analyse the results of the weighting of the VoC on the system level, we plotted the average (Figure 5.8) and variance (Figure 5.10) of the answers before and after the discussions. Three different results have been gathered in the same plots in order to study the effect of the discussion on the values and the effect of adding non-AL for the debate. To do so, we respectively compared the costs for the AL present to the meetings and the results for all the AL; and the values for all the AL who responded to the survey and the results of all the respondents (Quality engineers, Product Owners as well as Attribute leaders).

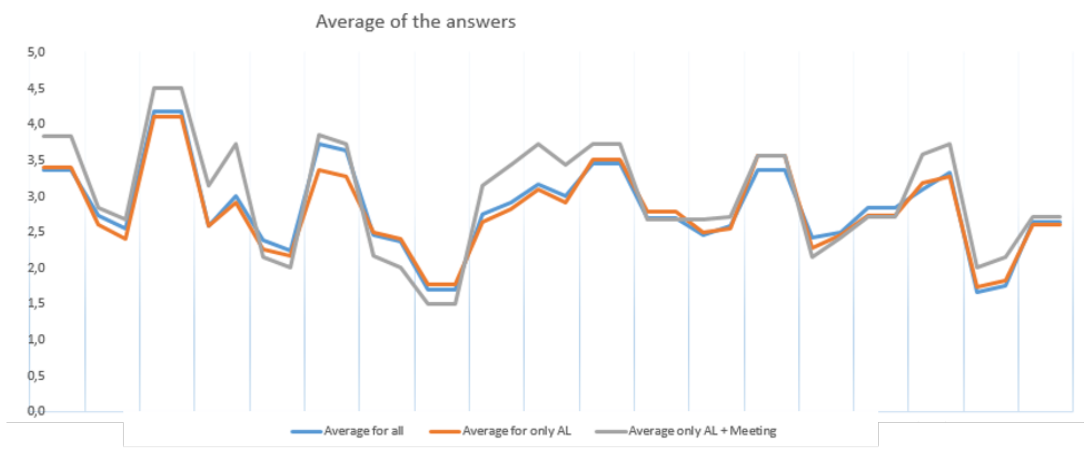


Figure 5.8: Average of the answers of the survey

As shown in Figure 5.8, the grey line tends to be higher than the others, which implies that when the AL is judging the VoC during the meeting, they tend to increase the value of each VoC.

This graph shows that three out of the four smallest weights concerns VoC that have been expressed by AL, who did not come to the meeting. This arrangement implies that the results can get unbalanced if the AL cannot come to present and defend their ideas to the meeting.

This fact highlights one weakness of our method since it could have been possible to scale all the VoC as "Very Important," so we should have compared the different VoC among themselves instead. Figure 5.9 shows that the votes values tend to get adjacent to the highest priorities.

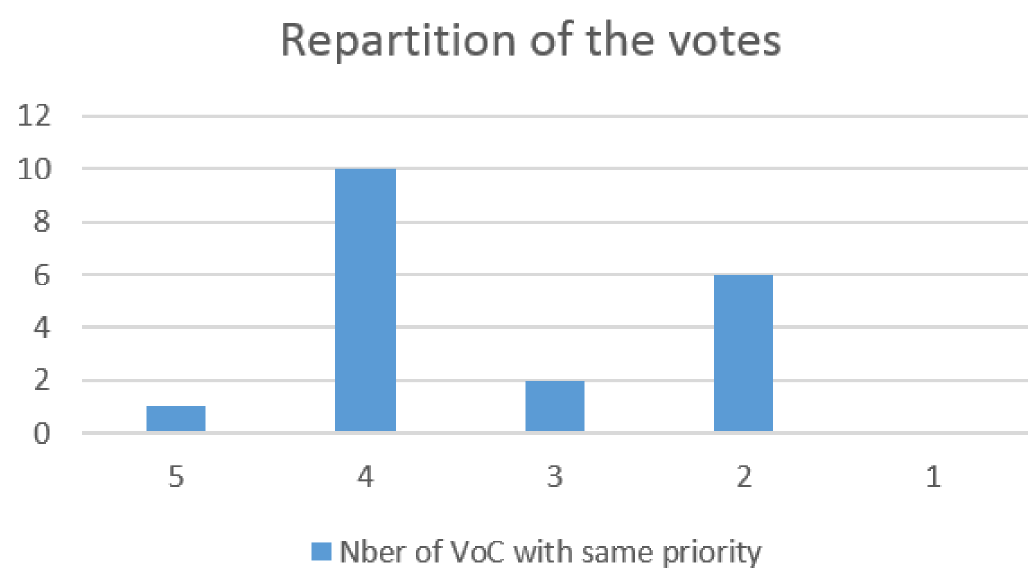


Figure 5.9: Number of VoC with the same priority (based on the votes of the AL for each VoC)

Moreover, we can highlight that even if more than 20 persons were invited to this meeting, not all of them attend, and this unbalanced the results since some Attribute Areas have been represented by two respondents while other areas were not represented at all.

Last but not least, we can see a group dynamic in Figure 5.8 since the average tends to decrease with time. This action suggested that even if we tried to go through all the VoC in the meeting introduction, it was not enough to give a fair and equal value to all of the VoC. To counterbalance that, it could have been relevant to randomise the VoC or to vote the first questions again at the end to measure the noise of the answers.

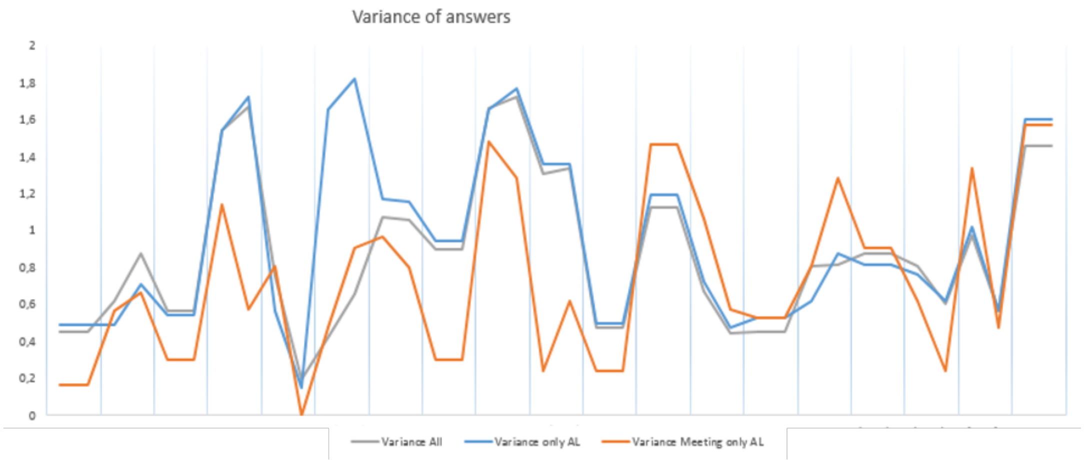


Figure 5.10: Variance of the answers of the survey

First of all, highlighting that the small amount of respondents to this survey tends to impact the values of the variances significantly.

The standard deviation of a sample can be calculated through the following expression:

$$\sigma_o = \frac{\sigma}{n^{1/2}} \tag{5.1}$$

σ is the standard deviation of the population and n is the size of the population (B.Bergman & B.Klefsjö, 2010).This calculation from equation (5.1) partly explains why the variance of the sample gathering all the respondents tends to be smaller than the other samples which have a smaller population size.

On the other hand, this graph emphasises the effect of the discussion on the opinions of the AL since the variance tends to decrease between the first and second votes. Moreover, in the case of the Safety - VoC, the variance is relatively low which is linked to the fact that all the employees at Volvo are aware that this is one of the core values of the company.

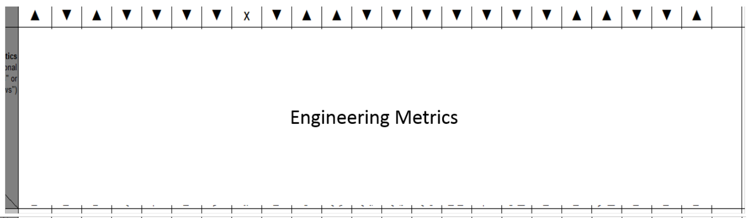
Furthermore, the variance tends to increase with the time, which could show that the stakeholders become bored by the survey and the meeting. This effect could be slightly counterbalanced by randomising the VoC. The variance tends to increase when the AL who are responsible for the VoC did not come to the meeting since they did not have the opportunity to explain and defend it.

In general, the survey has been an excellent mediating tool to help the stakeholders to express themselves anonymously during the meeting. The AL has particularly praised its interactivity since it created interactions and helped to keep the attention of all. Since the result of the votes were direct, the discussion was also facilitated. As mentioned earlier, the formulation of the VoC has been critical and has been underestimated by the project group.

In general, some learning has been drawn from this meeting, such as the importance of the fika considering it accommodated to produce side discussions during the break. Last but not least, the exchanges amongst the people showed that surely some of the senior stakeholders had misunderstandings on other area requirements, and the discussion raised awareness.

5.7.4 Final Results

As presented earlier in Figure 3.3 and Section 5.6, the modified HoQ allowed comparing the differences between the perspectives of the business and the AL on the relative importance of the engineering metrics of the system (Figure 5.11).



(0=Easy to Accomplish, 10=Extremely Difficult)																								
Max Relationship Value in Column	9	3	9	9	9	9	9	9	9	9	3	3	9	9	9	9	9	9	9		9	9	9	
Weight / Importance AL	326,5	94,0	164,9	259,1	68,0	95,1	59,6	261,5	77,0	130,3	35,9	36,5	170,1	87,6	66,0	94,8	31,2	160,4	161,4		202,1	89,7	70,6	
Relative Weight AL	11,9	3,4	6,0	9,4	2,5	3,5	2,2	9,5	2,8	4,8	1,3	1,3	6,2	3,2	2,4	3,5	1,1	5,8	5,9		7,4	3,3	2,6	
Weight / Importance Business	372,4	90,4	141,7	190,2	68,0	193,1	36,0	220,7	49,7	139,2	37,5	51,4	133,3	76,9	87,9	93,7	20,3	224,5	234,8		209,8	117,8	57,8	
Relative Weight Business	13,1	3,2	5,0	6,7	2,4	6,8	1,3	7,8	1,7	4,9	1,3	1,8	4,7	2,7	3,1	3,3	0,7	7,9	8,2		7,4	4,1	2,0	
Difference Business / AL	12,3%	4,0%	16,4%	36,2%	0,0%	50,7%	65,2%	18,5%	54,9%	6,4%	4,5%	29,0%	27,6%	13,9%	24,9%	1,1%	53,5%	28,5%	31,3%		3,6%	23,9%	22,1%	

Figure 5.11: Extract from the HoQ highlighting the differences between the AL and Business point of view

Figure 5.11 highlights a mismatch between the business- and AL perspectives since the three most crucial EM (the red cells in Figure 5.11) are different for each of them. The AL seems to target more functionality EM while the Business perspective tends to prioritise Styling requirements.

This mismatch can be explained by the predominance of Styling in the VoC on the vehicle level since 4 out of 18 VoC expressed on the vehicle level had been expressed by the PQ- or Styling areas. Notwithstanding that fact, it cannot be stated that AL is not aware of the styling needs since this aspect came back very often during the common meeting.

5.8 Feedback Quality Department

Since this QFD was one of the first of its kind being performed at Volvo, the team has been highly scouted by Quality coaches inside and outside the company. By pioneering the tool, the team had more freedom to modify the process described in theory to the specific context of the project.

The method which has been followed to do those two HoQ and the key learnings have been presented to the Hardware Quality team to help to improve the tool continuously.

First, the HoQ needed more time than expected and would have required even more time if we would have followed the theories of the QFD. This case highlights the fact that the method needs to be adapted to the context and the resources available. Despite the time required to be achieved, the HoQ seems to be very valuable to understand the needs in complex and inter-related systems such as the AS (for instance, in the relationship matrix that no EM or VoC is related to an individual element).

Consequently, it could be relevant to take the time to fill this HoQ a first time and then to update the weights and adapt the VoC and EM for the following projects. In this case, being master thesis students, this time allowed to gain a broad knowledge on the part in a relatively short period. On the other hand, this tool bolstered communication between all the stakeholders. Even if we had been told that gathering AL in the same room would be a challenge, it allowed discussion and explanation what the other areas have in mind. It also helped the engineers within the product team to understand how all the daily requirements are linked to the business side and beneficial to the customers.

The team additionally presented alongside modifications which have been done on the tool and created new templates to enable HoQ on a higher scale at Volvo Cars.

5.9 Conclusion

The HoQ helped to translate the customer needs to be expressed on the vehicle level into engineering metrics on the system levels. This tool is used to make sure that the final system - despite being hidden and unknown from the end customers - stays connected to the overall business intentions of the company.

The tool provided a ranked list of the engineering metrics, but it also offered a general understanding of how each customer needs and EM interact with each other. In that sense, this tool is useful to understand the interactions of complex systems. In this case, the three most crucial EM is different depending on the business or AL perspective.

Moreover, the HoQ gave an overall picture of the position of Volvo amongst its main premium competitors regarding the specified Customer Needs. Last but not least, as detailed in the discussion, this HoQ is a compromise between the theory defined in the literature and the Volvo' Way of Working since the resources needed must be balanced and adapted to the context.

6
Concept Development

This section of the report focuses on the development of the concepts, from the problem clarification, the different product development iterations to the final selection of the concepts.

6.1 Problem Clarification

As previously explained in Figure 3.6, the concept generation started with clarifying the problem to build strong foundations. This step sets the direction of the development, and it needs to be iterative during the process since new perspectives were uncovered on the way, during the innovation workshops, the meeting with the experts offering new ideas or closing other paths.

The connection between the problem clarification and the concept generation ensured a comprehensive picture of the problem and a stable foundation for future development within the project.

Due to its position in the front of the car, the part should withstand numerous noises such as ice, snow but also noises coming from customer usage. Following the GTDS guidelines, a study of the sounds was also included to include a comprehensive review of the noise which could potentially occur to cause error states.

The methods used for clarifying the problem was the Function-means Tree (Section 6.1.1), the P-Diagram (Section 6.1.2), as well as the Noise factor Management Diagram (Section 6.1.3).

6.1.1 Functional Analysis of the system - Function Tree

The Function tree is presented in Appendix C. It aims at dividing the full system into sub-functions and sub-systems. In this case, since all the functions are quite inter-related, the graph focused more on the functions than the means. This tool has been filled and checked with the support of the Design team.

By using this tool, it is possible to highlight how each product (from Volvo or other OEM) answers to the different sub-functions. For instance, the active spoiler shutter is automatically opened when the activator is shut down to prevent the vanes from staying locked (ice-locking issue) while Volvo never closes the AS when the temperature is judged as cold.

6.1.2 Identification of the noises affecting the system - P-Diagram

As explained previously in Section 3.1, the P-diagram is used to define the noises that may create Error States.

The P-Diagram has been done with Quality Engineers to benefit from their knowledge but also with Design Engineers to explicit what they already do during the development of the current parts.

The P-diagram is found in detail in Appendix D. The noises listed in the diagram show that the Environment has a significant impact on the part with, for instance, noises such as snow or dust. It shall not neglect the dimension variations that can affect the manufacturing of the part, NVH or other disturbances during the use of the product.

6.1.3 Ranking the noises affecting the system - NFM Diagram

The Noise Factor Management Diagram (NFM) is used to see how the noises are related to the state errors of the part. This analysis enables the design team to rank and identify the most significant noises. In this case, the matrix has been filled with Design Engineers and Design Engineers to catch the whole picture, and it is presented in Appendix E.

The three main noises which have been identified are:

- Assembly Variation
- Humidity / Ice and Snow
- Interactions with other systems

6.1.4 Creating An Initial Target Specification

As mentioned earlier, this project did not have any target project in mind which explain how there were not any target values. Consequently, the EM used in the HoQ, as well as Business Considerations, was used as specifications.

6.2 First Iteration - Conceptual

As presented earlier in Figure 3.5, the first iteration of the concept generation involves a large part of external and internal brainstorming with the organisation of Innovation workshops with very different people. Those alternatives were used to study the design space before using the Morphological Matrix to create the first generation of concepts, which were screened later in the process with an Elimination Matrix.

6.2.1 Interviews with experts and suppliers

The car gathers a tremendous amount of very complex systems which differ a lot (for instance, ICE, mirrors and lightning) which means that the knowledge in-house is likewise very extended. The AS is a unique system in the car, but its sub-functions are not, and they are already solved in other departments by different means.

Based on the Function Tree defined earlier, some sub-functions (e.g. ice-locking of the AS) have been identified in which other departments could have already worked on, such as the wipers, the closure mechanisms. Some meetings have been organised with stakeholders from those fields to understand how they cope with those sub-functions in their areas.

The market of the AS is divided between different suppliers who often have a whole department dedicated to the development of the parts. They often have very innovative ideas and have deep knowledge of the OEM demands. Consequently, three meetings have been organised to discuss suppliers and their concepts for BEV.

6.2.2 Innovation Workshops

As mentioned earlier in Section 3.4.1, the innovation workshops aimed to gather ideas outside of the box to make sure to investigate all the potential opportunities.

Four different workshops have been organised, gathering people from different backgrounds, as shown in the following examples:

- People with a Quality background, enabling them to understand the system at a large scale
- Group Managers
- System Responsible having comprehensive technical knowledge on the full Exterior Front Systems
- Master Thesis Students without any experience from the system to bring additional approaches
- Design Engineers and Group Design Leaders from the team (specialised in Manufacturing or development)
- Product Owner of the Shutter system
- Concept team

Some mediating tools have been used, such as a presentation or inspiring quotes. All the participants were asked to draw or write to papers or post-its to be able to present their ideas to the group, as shown in figure 6.1.

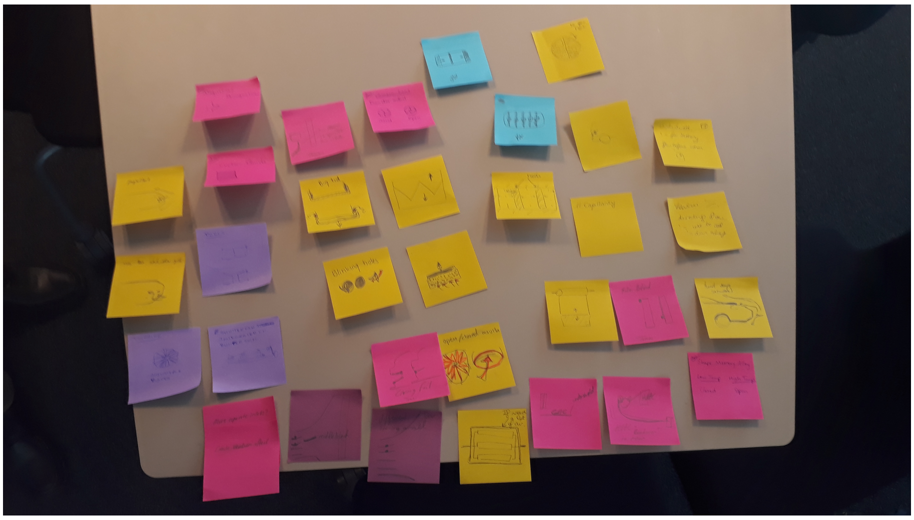


Figure 6.1: Post-Its resulting from an Innovation Workshop

6.2.3 Brainstorming and Concept trees

More individual and group brainstorming have been organised within the group in order to find solutions to the individual functions or current issues of the product. Examples of these individual functions are; preventing the dust to come inside the engine bay, control the air flow, etc while examples of the current issues are, prevent the mechanism to freeze, optimise the dispersion of the flow on the cooling pack.

In order to organise the results of a brainstorming and deepen it, Concept trees can be used.

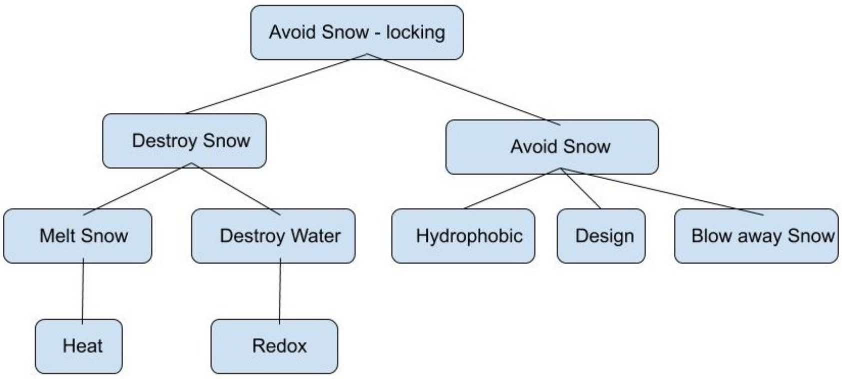


Figure 6.2: Example of a concept tree for "How to prevent the mechanism to freeze?"

6.2.4 Morphological Matrix

Having carried out the brainstorming sessions, and with the support of the innovation workshops, the generated concept ideas to solve each function were placed into a morphological matrix to list all the alternatives for each respective function (K. T. Ulrich & S.D.Eppinger, 2012).

Individually and based on this morphological matrix, each team member created their own concepts as shown in Figure 6.3. After that, the ideas have been merged to avoid redundant or too much similarity into 18 new concepts. It was essential to making sure that those concepts kept a vital level of differences since no screening happened at that step.

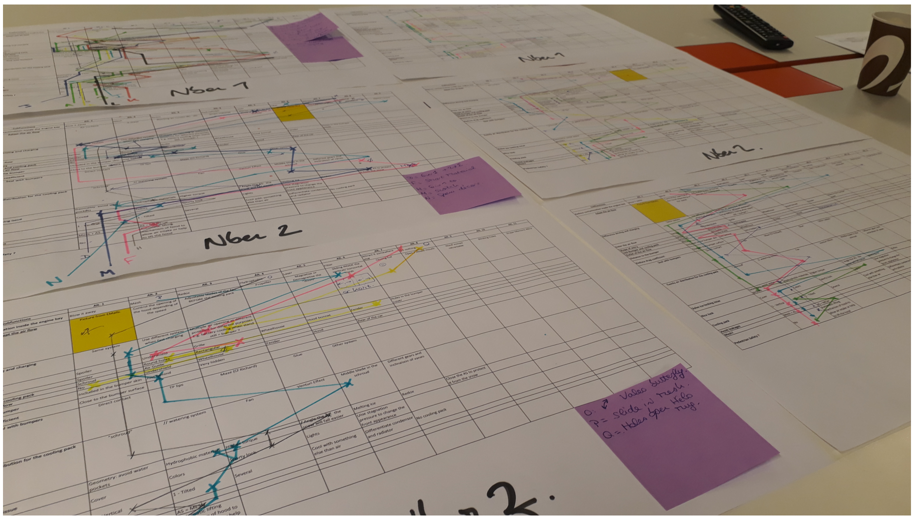


Figure 6.3: Example of a Morphological Matrix

All those concepts were named to be easily recognised and characterised by a few lines to facilitate their understanding amongst the team.

6.2.5 Elimination Matrix - Elimination of unfeasible concepts

As described previously in Section 3.4.3, the first method used to sort the concepts was the Elimination Matrix.

An extract of the Elimination Matrix can be seen in Figure 6.4, where the generated concepts gathered in the first row of the matrix, and the criterion is listed in the first column on the left.

	A= Textile curtains	B= Shop curtains	E= Vanes as today with additional holes in the fender for Fast Charging	F= Camera Lens	J=Sliding in the mesh	K= vanes + Holes in the hood + Safety functions	O= Valeo butterfly	Z= Today in the bumper	X= Sliding in the undershield	ui
Criterion A: Solution proposals are compatible with the overall task and one another.	Y	Y	Y	Y	Y	Y	Y	Y	Y	
Criterion B: The solution proposals fulfil the demands of the requirements list.	Y	Y	Y	Y	Y	Y	?	Y	Y	
Criterion C: The solution proposals are realisable in respect of performance, layout, etc.	Y	?	Y	?	Y	N	?	Y	?	
Criterion D: The solution proposals are expected to be within permissible costs	Y	?	?		?		?	?		
Criterion E: incorporate direct safety measures or introduce favourable ergonomic conditions										
Criterion F: are preferred by the designer's company										
Criterion G: Distance to the bumpers	Y	Y	Y		Y			Y		
Criterion H: Maximal area without mesh	Y	Y	Y		Y					
Criterion I: Stiffness of the part	?	?	Y		?					
Criterion J: Fit to Volvo Design				Y	Y			?		
Conclusion	Y	Y	Y	// J	Y	N	Y	Y	// F	

Figure 6.4: Extract from the Elimination Matrix

All the generated concepts have been confronted against the selected criterion. Those criteria gather the general criterion from the literature (G. Pahl & W. Beitz, 2013) but also the three most crucial engineering metrics from the perspective of the AL (from the HoQ - Table 5.4).

Since all those concepts were defined at a high level, some criterion had to be neglected, such as "the preference from the company's designers." Moreover, it is not always possible to have an answer for all of the criterion, and this is why the "?" has been introduced in the matrix. The concepts that failed to fulfil one or more criterion are marked in red and were subject to elimination.

Furthermore, the ideas that have been assessed too comparable have also been rejected or merged, and they have been marked in yellow.

When the matrix evaluation was finished, ten concepts were eliminated, and eight remained.

6.3 Second Iteration - Development and screening of the concepts

The second iteration of the project started from the results of the Elimination since the remaining concepts were detailed and then screened based on a Pugh Matrix as well as Engineering Judgement from the main stakeholders and AL of the project.

6.3.1 Concept Development and Tests

In Figure 3.5, some inspiration from the eliminated concepts has been used to improve the selected concepts.

Moreover, the concepts have been detailed described by applying continuous external and internal benchmarking.
Some quick and dirty prototypes have also been used it test the different possibilities. Some papers have been used as well as basic CAD models.

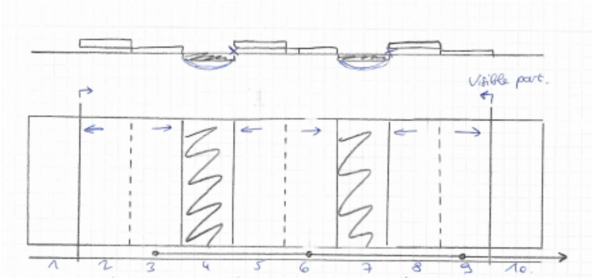


Figure 6.5: Detailed Design of "Sliding in the Mesh" Concept

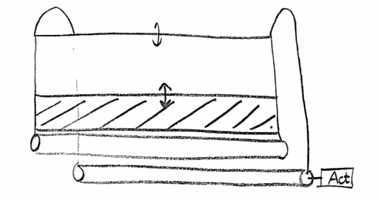


Figure 6.6: Concept of double curtains

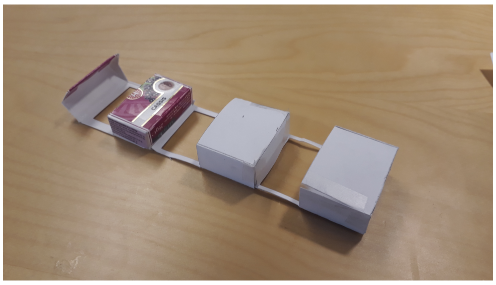


Figure 6.7: Prototype of the "Shop curtain Concept"

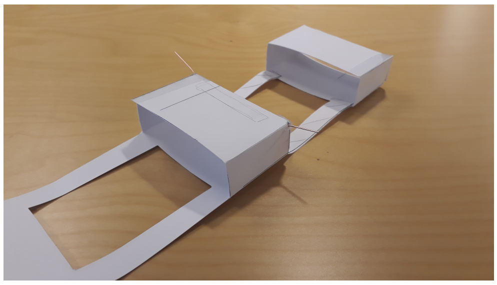


Figure 6.8: Prototype with an increased size of the opening

Furthermore, additional interviews have been organised with experts to determine the limitations or opportunities of each technology to be able to improve the concepts.

6.3.2 Screening of the concepts - Pugh Matrix

As described previously in Section 3.7, the second method used to sort the concepts is the Pugh Matrix.

An extract of the Pugh Matrix can be seen in Figure 6.9, where the generated concepts are gathered in the column on the left, and the criterion is listed in the first row of the matrix.

Pugh Matrix

Concept Selection Legend	
Better	+
Same	S
Worse	-

Key Criteria	H	VC	DVC	ZigZag Sliding	ZigZag Cocotte	Shop curtains	Extenso	Sliding behind	Sliding in the mesh	AS as today with 2K vanes	AS as today with Decrease thicker central part	Central joints (No middle support but supports for each lines)	Slidable middle part	AS as today with Joint with structure	AS as today with Hood wing	AS as today with Tilted Cooling pack	AS as today with Tilted Cooling pack + alternative air/intake	Vertical Vanes
	Solution Alternatives																	
Air flow leakages between the front and the cooling pack [%]	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Airflow passing the condensor while driving and with an CLOSED AS [Kg/s]	+	+	+	-	-	+	S	+	+	+	S	S	S	S	S	S	S	S
Airflow passing the condensor while driving with an OPEN AS [Kg/s]	+	+	+	-	-	-	S	-	-	S	+	+	S	+	+	S	-	+
Airflow passing the condensor while standing still with an OPEN AS [Kg/s]	+	+	+	-	-	+	+	-	-	S	+	+	+	+	+	S	+	+
Area of opening [mm2]	S	S	S	S	S	S	S	S	S	S	S	S	S	S	+	S	+	S
Complexity	-	-	-	-	-	-	-	-	-	-	-	-	-	S	-	-	-	-
Compressed length of AS [mmx]	+	+	+	+	+	+	S	+	+	S	S	S	S	S	S	-	-	S
Distance to the bumper [mm]	S	S	S	+	+	S	S	S	+	S	S	S	S	S	S	S	S	+
Drag Coefficient Cd*a	-	-	-	+	+	-	S	+	S	S	+	+	S	S	S?	S	+?	+
Durability / Robustness	-	S	S	-	-	-	-	-	-	+	-	-	-	-	S	S	S	-

Figure 6.9: Extract from the Pugh Matrix

As showed in Figure 6.9, the system used for project X has been used as a reference to compare the other concepts.

To stay focused on the performance of each concept, the cost of each idea has been estimated following a similar system of comparison (from -3 to +1), and the result is presented in the following Figure 6.10.

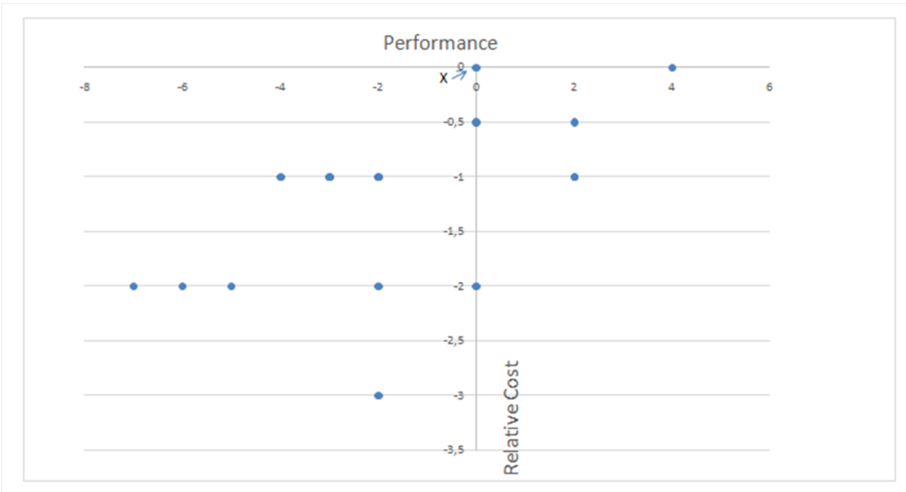


Figure 6.10: Performance and cost of the different concepts compared to the current concept

From this first step, four different concepts have been removed from the selection, and a second Pugh matrix has been done using another reference. The double vertical curtain has been selected due to its discrepancies to the different concepts.

In parallel with the Pugh matrices, several interviews have been organised with some of the central stakeholders to use their engineering judgements to compare the concepts objectively. Those individual meetings have been held with the AL of Thermodynamics and Aerodynamics, two principal engineers or the Concept team, one of the System responsible (SA) of the exterior font ART to benefit from technical knowledge and lastly the function owner of AS.

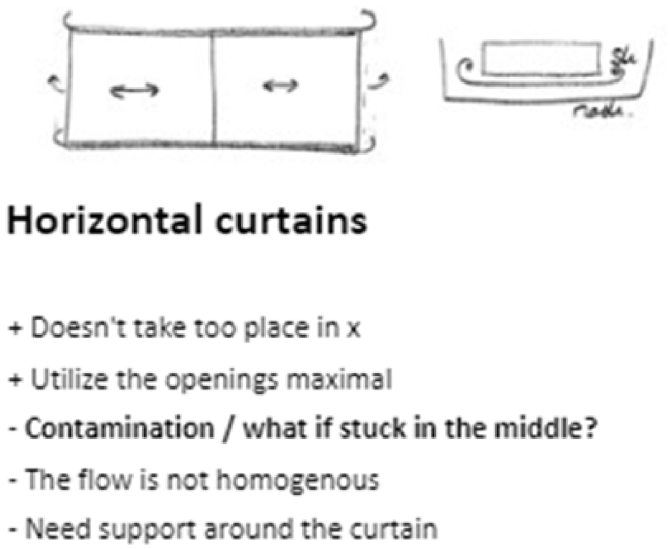


Figure 6.11: Extract of the presentation detailing the advantages and weaknesses of each concept

Consequently at the end of this process six concepts remained. The other concepts have been merged or carefully examined to catch their positive aspects to improve the remaining concepts.

6.4 Third Iteration - Final Development and scoring of the concepts

The third and last loop of this master thesis project focuses more on the particular concepts by taking the full life cycle of the ideas into consideration, such as their manufacturability or complexity. Moreover, this loop measures the performance of the concepts for each of the customer needs gathering in the HoQ.

6.4.1 Concept Development and Tests

Following the end of the Pugh Matrix, the results were merged in order to keep the best aspects of the rejected concepts.

For the final concept generation iteration, a specific focus has been done on the feasibility of each concept, such as the manufacturing of each concept. Since the system is anticipated to be in polymers, a mould-flow expert has been consulted as well as different material experts.

6.4.2 Scoring of the concepts - Kasselring Matrix

As described previously in Section 3.8, the second method used to score the concepts is the Kesselring Matrix.

The first step was to define the criterion, their levels as well as their respective weights. As shown in Table 6.1, most of the criterion is based on HoQ data collection. Since the part should be used in an environment containing noises, it was decided to include criterion taking into consideration the resilience to the main sounds (for instance "Resilient to the noise factor of dimension variations"). Furthermore, some criterion has been added to measure the business case of each concept (for example, "the capacity to carryover parts between projects").

Category	Requirements
Cost	Cost
Durability	Durability / Robustness
Feasibility	Feasibility
Manufacturability	Manufacturability = Resilient to the noise factor of dimension variations
Packaging	Packaging consequences / Impact on the other systems
Performance	Airflow passing the condenser while driving with an OPEN AS [Kg/s]
	Airflow passing the condenser while standing still with an OPEN AS [Kg/s]
	Thickness of the part [mm]
	Pressure difference on the cooling pack [Pa or Kg/s]
	Number of visible openings []
	Time needed to open/close the shutter [t]
	Ice locking Errors (%) / Resilient to the Noise Factor = ICE
	Airflow passing the condenser while driving and with an CLOSED AS [Kg/s] (Sealing)
	Compressed length of AS [mmx]
	Useful opening (real front opening/total front surface) [%]
	Area of visible opening in front of the car [mm2]
	Maximal area without mesh [mm2]
	Stiffness of the part []
	Number and Severity of appearance issues
	Fit to Volvo design
	Distance to the bumper [mm]
Portability	Portability = capacity to carryover parts between projects
Weight	Weight of the part [Kg]

Table 6.1: Criterion used for the Kesselring Matrix

The relative importance of each category (for example, Cost, Durability, Performance) was decided with the Product Owner of the AS while the relative weights within the "Performance" category are retrieved from HoQ data (Section 5.6).

Those criterion defined in the previous table can be subjective, and that is why it is critical to establish objective scales in order to be able to judge them with objectivity (by example in the Figure 6.12, the weights are examples, and the order of the VoC is not linked to their relative importance).

B	D	E	F	G	H	I
Key Criteria	**Relative importance**	**1**	**2**	**3**	**4**	**5**
Distance to the bumper [mm]	1,58%	No active shutters / condensor level	-15cm	-10cm (at the crash bin level)	-2cm (Position of X)	0cm (integrated to the A surface)
Number of visible openings []	1,58%	4	3	2	1	0
Useful opening (real front opening/total front surface) [%]	0,60%	70% (when driving AND charging)	80% (when driving AND charging)	90% (when driving AND charging)	100% (only when charging) 90% when driving	100% (when driving AND charging)
Area of visible opening in front of the car [mm2]	0,60%		Should increase the opening area	X	Can reduce the opening area	0
Thickness of the part (AS) [mm]	0,29%	>70 mm	55-70 mm	40-55 mm	30-40 mm	<30mm
Maximal area without mesh [mm2]	0,29%	No ribs	Longer distance between ribs than Y	// Y	Ribs closer than Y	Closed surface

Figure 6.12: Extract from the scale used for the Kesselring Matrix

An extract of the Kesselring Matrix can be seen in Figure 6.13, where the list of the criterion is in the column on the left, and the concepts are in the first row of the matrix.

Key Criteria	Importance Rating	Solution Alternatives: Horizontal Curtains	Vertical Vanes in bumper	Extenso	{Improved Vanes} in bumper	{Improved Vanes} in x=5cm	Double air-intake
Airflow passing the condensor while driving and with an CLOSED AS [Kg/s]	#	4	3	2	4	3	2
Airflow passing the condensor while driving with an OPEN AS [Kg/s]	#	5	4	2	3	2	3
Airflow passing the condensor while standing still with an OPEN AS [Kg/s]	#	5	4	4	3	3	5
Area of visible opening in front of the car [mm2]	#	4	3	3	3	3	4
Compressed length of AS [mmx]	#	4	3	2	3	3	3
Distance to the bumper [mm]	#	4	5	5	5	4	4
Durability / Robustness	#	2	3	1	4	4	2
Feasability = Development costs needed to create the part	#	1	3	1	3	4	1
Fit to Volvo design	#	2	4	2	4	3	4
Ice locking Errors (%) / Resilient to the Noise Factor = ICE	#	1	2	2	2	3	4

Figure 6.13: Extract from the Kesselring Matrix

For each criteria, the concepts have been judged based on the scale defined (Figure 6.12) from 1 to 5.

The final score is presented in the Figure 6.14:

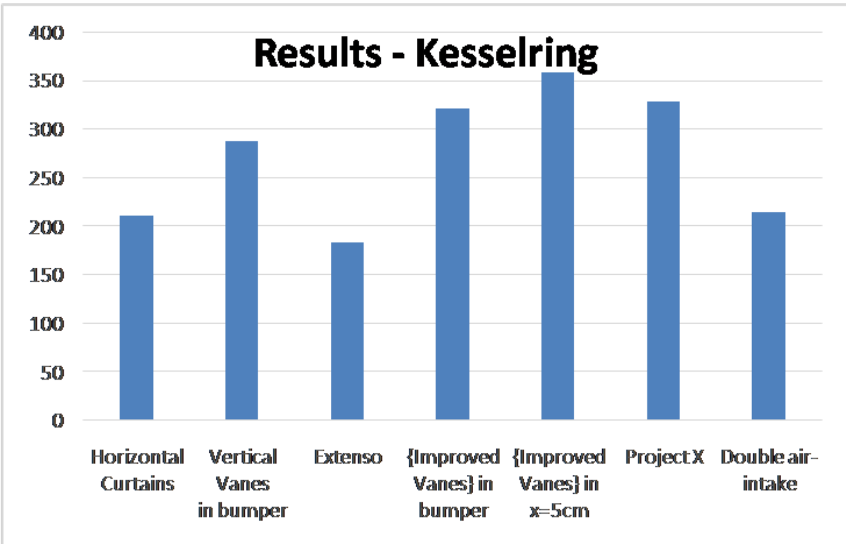


Figure 6.14: Scores of the different concepts

The concept "Improved vanes integrated to the bumper" is relatively similar to the "Vertical vanes in the bumper" as well as the "Improved vanes and hidden." In order to keep a variety of various concepts for the detailed design, it was decided to merge the horizontal and vertical visible vanes. Based on the concepts score, this merge was decided to keep the resulting three concepts for the final refinement:

- Improving vanes and keeping the concept of project X with x=5cm
- Improving (horizontal and vertical) vanes with x=0cm

- Double air-inlets

As visualised in Figure 6.14,the best concept created through the project has increased by 9,1% the performance of the project X (already developed by Volvo).

6.5 Discussion

This Section reviews the Concept Generation and Selection processes to analyse the results and draw an intermediate conclusion on that second milestone.

6.5.1 Innovation workshops

The innovation workshop is relatively different from a daily engineering task since they require enhanced creativity. It is critical to understand how each individual has its ways to enter a "creative mode," and the prepared PowerPoint slides were the best way for the team but not especially for everyone.

Moreover, engineering responsibilities require knowing the limits of the products that are developed, to understand the requirements, what has already been investigated, what seems too complex to be realised right now, and it is particularly complex to put aside all those aspects to think "outside of the box." Even if it was attempt to blend the background and knowledge levels throughout these innovation workshops in order to create more interaction, the team did not manage to create real discussion.

The formulation of the question was also critical considering it should not be too comprehensive to avoid confusing stakeholders but being too narrow prevent them from going outside of the box. Consequently, a balance needs to be found, and the question could have been changed depending on each stakeholder. Other methods, such as writing ideas and forwarding them to one neighbour who has to add elements could be an alternative in order to create more synergies amongst the participants.

6.5.2 Morphological Matrix

As presented earlier in Section 6.2.4, the morphological matrices enabled the team to create the first generation of concepts using the ideas described by the participants during the innovation workshops as well as internal and external brainstorming.

Up to twenty different alternatives described some sub-functions while others had just a few of them. Consequently, even if many concepts have been created, they were often variants of each other.

Furthermore, while creating the concepts, some troubles have raised since not all the alternatives were at the same level. Sometimes possible to pick a combination of several options to fulfil a single sub-function (for instance, in the case of "water-tight," it could have been relevant to include all the other options to make the concept more resilient to ice-locking issues).

On the other hand, by studying at the newly created concepts, it is reasonable to see that they stayed inside the box. Moreover, by considering at the matrices, a pattern can be distinguished since most of the alternatives have been chosen on "the left side of the matrix" as viewed in the 6.15.

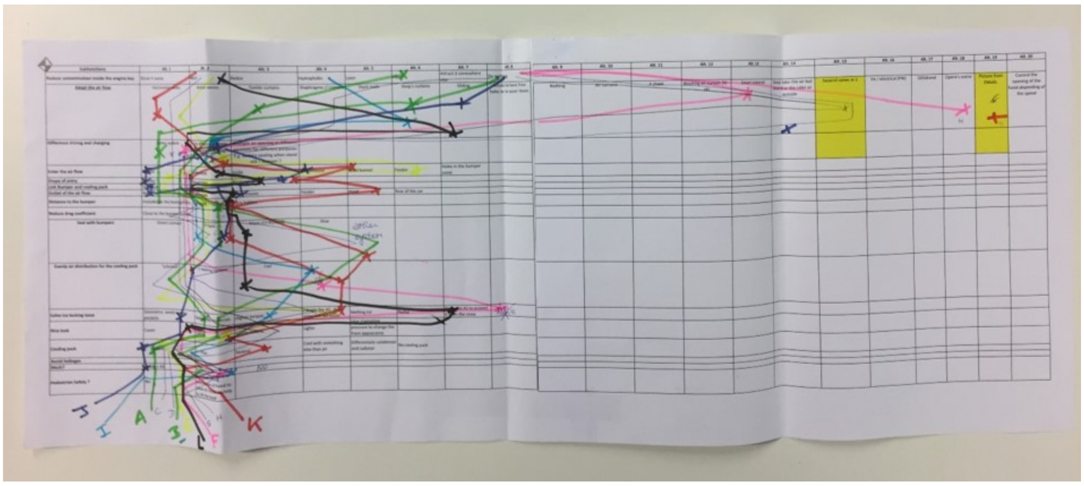


Figure 6.15: Picture of a Morphological Matrix showing the trend to select alternatives on the left side

Finally, it could have been relevant to include people from outside of the master-team to create those concepts in order to keep "thinking outside of the box" and making sure that all the original ideas generated throughout the innovation workshops were saved and turned into concepts.

6.5.3 Elimination Matrix - Eliminating concepts

As described earlier in Section 6.2.5, the elimination matrix was used in order to do a first rough selection amongst the concepts.

Since the concepts were created from the Morphological Matrix, they were highly conceptual, and it was relatively difficult to be able to compare and judge them with the knowledge within the master thesis team. Since the Technology Readiness Level (TRL) of the respective concept was very inconsistent, it was tough to judge if they were realisable or not at that time of the project.

In order to judge the concepts, general and project-specific criterion were used, but since those latest were design-related, they should have been adopted or not taken into consideration that early.

6.5.4 Pugh Matrix - Scoring the Concepts

The Pugh Matrix was used in Section 6.3.2 in order to screen the concepts.

Since it was only the second iteration, it was decided to retain the equal weight for respectively, but that may have created an unbalance among the concepts: making compromises may bring drawbacks on particular criteria, but the general result may be improved at the system level. Furthermore, the concepts were judged toward three-level scales, and again, a five-level scale may have helped to identify the difference between "small improvements" or "main improvements." On the other hand, those choices were made, and since a Kesselring matrix was supposed to be carried out subsequent, it would have been redundant and time-consuming to use such a detailed matrix.

As described previously, two different Pugh matrices was carried out with varying references to compare the results. Moreover, at that stage of the project, the concepts were still not-detailed enough to include simulations or tests. Thus the matrix has been filled based on the Engineering Judgement of the team.

In order to counterbalance this effect, the judgements of Attribute Leaders and concept engineers were also included to help to understand the advantages and drawbacks of each concept.

Unfortunately, some questions could not be solved entirely by engineering judgement, and some tests should have been carried out to measure the value and cost of each idea objectively. Likewise, if the team tried to investigate those simulations and experiments, they were too complicated and time-consuming to implement, for instance, ordering parts, requesting a test, waiting for the analysis to be carried out.

It was decided to keep the Cost aspect outside of the Pugh Matrix to compare separately and distinguish the value and cost of each concept. As mentioned earlier, it was relatively hard to assume values, but it was also particularly hard to interpret. Despite that, it can be seen that all the new concepts tend to be more expensive than the current project, which was used as the reference.

6.5.5 Kesselring Matrix - Scoring the concept

The Kesselring matrix presented in Section 6.4.2 was used to score the different remaining concepts.

The first step was to select and weight the criterion. Even if the product owner supported to the weighting of the different "general" criterion (such as "Performance," "Weight," and "Durability"), it was especially hard to compare them. It could have been relevant to use a hierarchical comparison to be able to rank them, but at that time of the project, there was not enough time to use that tool. On the other hand, the HoQ was utilized for weighting the different criterion inside the "Performance" headline, and it felt quite confident to know that those weights come from the business side.

The second step was to define the scale of the criterion. This step is critical to creating an objective scale, but this is particularly complex when the criteria are subjective such as the "aesthetics." Again, testing would have been beneficial at that time of the project.

The last step was to compare the different concepts to those scales. As mentioned earlier for the Pugh matrix, it was extraordinarily complex to judge those concepts based on the Engineering Judgement of the team as well as the Attribute leaders' one. Again, tests and simulations would have helped to compare more objectively the concepts.

Due to the different weights, we can see how the cost and other business parameters tend to squeeze the performance of the part. Finally, the Figure 6.14 shows that the consequences of each concept are quite close to each other, and a sensibility analysis could be carried out in order to measure the variations of the outputs compared to potential weight-variations.

As mentioned earlier, the overall performance of the best concept is better by 9,1% compared to the concept X. This is 55% less than what was targeted by the aims of the project and this can be explained by several reasons.
First, the part has been used and developed by engineers for several decades and some suppliers employ whole departments to develop AS. The increasing competition between suppliers incite them to put an extra focus on optimisation to satisfy OEM. Moreover, the automotive industry tends to be conservative since cost efficiency is a driving factor for all choices.
Last but not least, the front block of the vehicle gathers already a tremendous number of parts such as metal-structures for the body, the cooling system, electronic sensors and safety structures. All those parts need to co-habitate in a limited space therefore packaging compromises are really critical.

6.6 Conclusion

The concept generation, as presented earlier in Figure 3.5, enabled the project team to ensure that the design space was thoroughly investigated by including, for instance, external- and internal benchmarking or innovative workshops.

The iterations of the project enabled a selection of the concepts as objective as possible and ended with the three most promising designs. Although they remain at a concept level, it would have been necessary to carry out further simulations and testing to be able to distinguish them or measure their results with a unbiased judgement. The three final concepts are more deeply detailed in the following Section 7.

7

Final concepts

This Section details the three final concepts: the Classic, the Other, and the Synergy. Each of them presents a potential direction for the AS strategy.

7.1 The classic - Horizontal vanes with x=5cm

This concept is quite similar to the current concept X or the other concepts developed by the other OEM.

- The AS stays hidden (behind the spoiler mesh) for styling and contamination requirements.
- The AS is composed of 2 arrays of moving vanes. The size of the bumper-opening determines the number of vanes.
- The two arrays of vanes are linked behind the central link.
- The activator as in all Volvo projects would lay on the side of the AS to prevent it from damaging the cooling pack in case of a crash (Allianz test).

7.1.1 Detailed design:

- In order to decrease the perturbation created by the vanes on the air flow, it could be suitable to design the vanes as plane profiles.

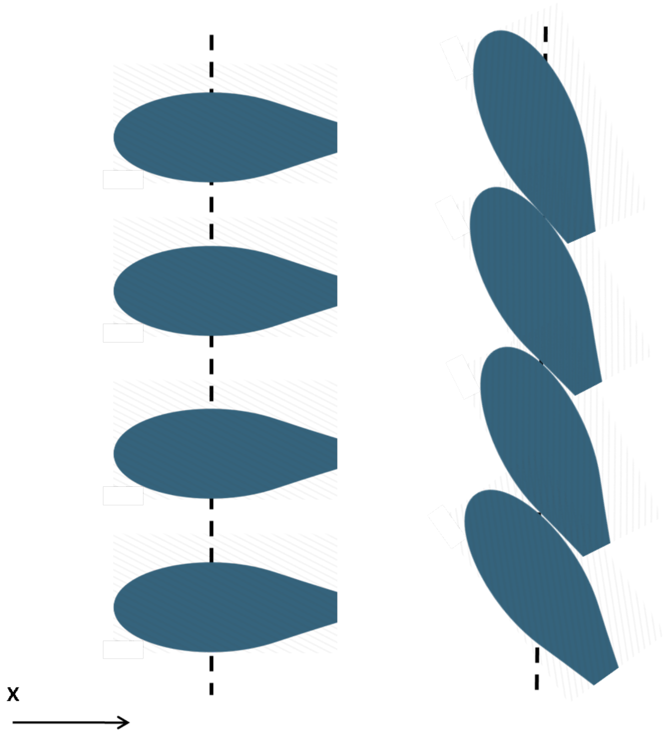


Figure 7.1: Vanes designed with the shape of a water droplet

- In order to improve the efficient air flow entrance, it could be critical to investigate the area of the middle part linking the two sides of vanes. This central part could be reduced or even eliminated in the case of long-length vanes. Several solutions have been considered:
  - The solution used by Renault in Scenic or Kadjar models (Figure 7.2) and described earlier could be investigated for Volvo. This solution uses longer vanes (more than 570mm) with three vertical supports (which could be aligned with the mesh).

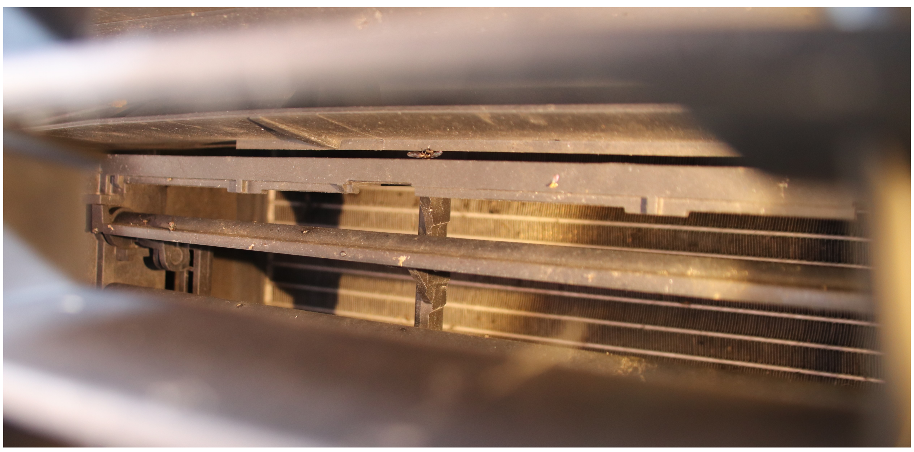


Figure 7.2: AS of a Scénic (Renault)

Since the support is hidden behind the shutter, this solution could be more aesthetic than X. Moreover this solution decreases the number of parts required since we divide the number of vanes by two.

– Following several discussions with material experts at Volvo, it was concluded that the middle part could be slimmed down by using optimisation.

For all those alternatives, it is critical to carry out further investigations to measure the real benefits of reducing the size of this middle support to compare it with the cost.

- The current middle part of the AS for project Y is created by two flat surfaces perpendicular to the entering air flow. Those flat surfaces hinder the air flow, and it would be highly suitable to use curves instead (by example, BMW series 2) as shown in Figure 7.3 marked by the red arrow.

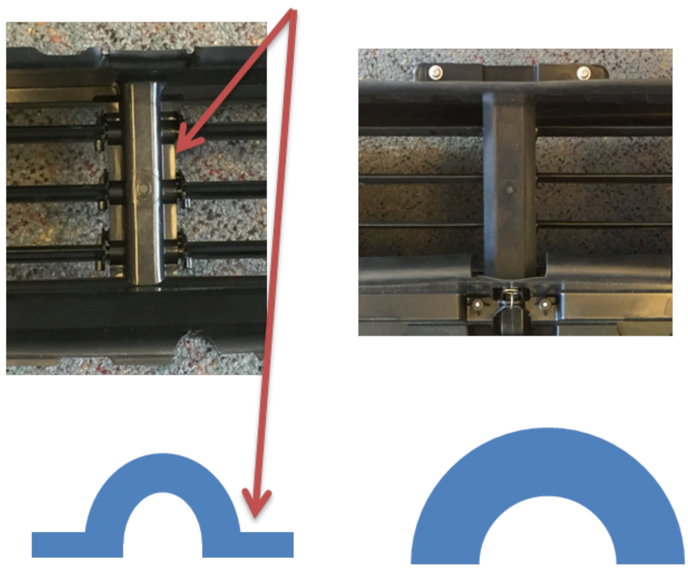


Figure 7.3: Comparison between the Volvo Y and a BMW Serie 2.

- When the vanes are closed, the sealing with the housing is provided by a structural stop which is integrated into the housing. Tesla or BMW managed to reduce the size of this stop drastically, and this could likewise be investigated at Volvo.

- As noticed throughout the master thesis project, the dispersion of the airflow over the cooling pack is critical for the cooling performance.

  Several (confidential) solutions have been considered and It has been concluded that optimising the shroud could be one of the direct ways to maximise the airflow on the cooling pack since it avoids adding any disturbances to the air flow.

- Regarding the control of the AS, it could be interesting to study further profoundly the number of steps necessary.

- The cold markets should be further investigated. In this case, the power of the battery is used to ensure a minimum temperature (to guaranty the efficiency of the battery) which implies that the active shutter should be closed to avoid losing the heat produced inside the engine bay. This strategy goes toward the current method used by Volvo to prevent the vanes from freezing during the winter (in case of closed vanes, it would be almost impossible to fast-charge the vehicle).

- While the bumper and surroundings of the vehicle may change between the several projects, the vanes are standard. The modularization of the system could be studied to see the benefits of the long run of carryover more parts.

7.1.2 Material Considerations:

The Polypropylene (PP) is a combination of alkaline chains which makes it very non-polar. Due to this hydrophobic property, the PP tends to avoid interactions with polar molecules such as water. Consequently, adopting vanes in a composite created with a matrix in PP and reinforcements in Glass Fibers (PP+GF) could accommodate to prevent the ice-locking issue.

As describe previous the active shutters are is hidden in today Volvo vehicles, so adopting PP could also be an opportunity to use recycled materials to help to reach the target of the 25% of recycled materials by 2025. It could likewise be interesting to consider the consequences of the shark skin on the vanes to reduce the resistance.

7.1.2.1 Manufacturing the part:

In the case of reducing the size of the central part of the housing, this may create challenges for housing manufacturing. This central support section is applied throughout the housing injection to create constraints to maintain the rectangular shape of the housing and preventing it from collapsing.

Several alternatives have been considered to prevent this failure:
- In the case of just reducing the size of the central part, it is necessary to use smaller injection gates as the size of the current entrance is the bottleneck of the central section (at least on the Y). To counterbalance the size of the injection gates, it could be reasonable to use a combination of them. In this case, it is critical to keep the joining lines, which are structural weaknesses.
- Another solution would be to utilize support when the housing is cooling down to keep the shape.
- As mentioned earlier, Renault has smaller vertical ribs, and Volvo could investigate wherewith they are manufactured.

7.1.3 Summary - The Classic

+	-
Easy to Implement	No real improvement on the drag
Knowledge already in-house	No significantly more air flow
No variants needed for each trim level	

Table 7.1: Summary of the Classic

7.2 The Other - AS integrated to the A-Surface of the bumper

This concept is also relatively similar to the current designs developed by Volvo, but it is also inspired by the lung-grille from BMW or Mercedes or the Spoiler shutter utilized in the Porsche 911 as illustrated in Section 4.4.2.

- The AS is visible (it is integrated into the spoiler mesh in the A-Surface) to improve the performance of the shutter system and supplement a styling value.
- Two different set-ups can be used:
  - The same concept of horizontal vanes can be used Section 7.1.
  - Vertical vanes. They are linked from the side.

  In both cases, the AS is composed of several vanes determined by the area of the bumper opening.
- The activator as in all Volvo projects would be placed on the side of the AS to prevent it from damaging the cooling pack in case of a crash (Allianz test).

An example of Vertical AS can be found at BMW as seen in Figure 7.4:

Figure 7.4: Kidney grille integrated with an AS on BMW Serie 7 (BMW, 2015)

7.2.1 Specific requirements on the mesh

Since the shutter is integrated into the bumper mesh, most of the requirements lying on the latest may further become applicable for the shutters.

First, we should keep in mind the cost perspective of the current system produced in polymers and chrome or painted, which is relatively cheap corresponded to the cost of an AS (sometimes ten times more expensive).
Moreover, since the bumper is assembled in a pre-assembly station, the AS would support a similar principle. If the bumper becomes too heavy, it would need reinforcements and could generate flashes and gaps at its boundaries. Consequently, it is critical to tighten the requirement on the weight of the part.
Furthermore, it could influence pedestrian safety since the AS would risk being stiffer than the current mesh.
Last but not least, the AS should be capable of resisting the low-speed crash without being damaged. This fact increases the requirements on the robustness of the mechanisms which should withstand collisions below $30Km.h^{-1}$.

As it was already reported in the benchmarking part, Porsche is the exclusive OEM utilising visible AS on the spoiler section in the front of its cars (the wheelhouse), and no other OEM has integrated spoiler AS yet.

The organisational aspect should also be mentioned since as today, the mesh and AS are developed in the same ART but by different teams who have never worked together. Each development team has its own Way of Working, suppliers, or contacts among Volvo.

7.2.2 Detailed Design

Those two concepts request for further development since no AS integrated to the A-surface were developed beforehand. Also, the developments needed before being integrated into a vehicle are even further consequent for the case of the vertical vanes since it requires a complete re-design of the mechanisms linking the vanes.

As explained in the following Section, including the Shutters on the A-surface significantly elevates the prerequisites on the styling and PQ requirements or the materials applied. In this case, it is significant to measure precisely the value of doing it to check the business case such as the impact upon the drag of the vehicle C_dA.

One viewpoint which should not be neglected is the portability or the capacity to carry-over parts between projects or trim-levels. As soon as the shutter system is noticeable, the styling department may require different variants for each version, multiplying by three the number of modifications needed for each project.

7.2.3 Material considerations

By including the shutters on the A-Surface of the bumper, the styling and PQ requirements are tightened. This action likewise increases the level of other attribute areas such as the corrosion or the resistance of the part to the stone-skipping. In order to understand this consequence, it could be interesting to study the material decision of BMW for its grille or the choice of Porsche for its spoiler shutter.

7.2.4 Manufacturing Considerations

In the case of horizontal vanes, considerations are the equivalent as those mentioned earlier in the Section 7.1.2.1. Regarding vertical vanes, the intention is not entirely to reduce the size of the central part but to remove it entirely since the vanes are stiffer enough to avoid bending in the x-direction.

7.2.5 Summary - The Other

+	-
Improved performance (Aero)	Increased level of requirements
Improved Value for Styling	More Variants
	Potential increased cost

Table 7.2: Summary of the Other

7.3 The Synergy - Using two air inlets

In the case of the BEV, the bottleneck of the cooling needs is principally established through the fast-charging requirements. Cooling the vehicle when the car is standing still opens new opportunities but also new challenges since there is no airflow circulating the vehicle (when the fan is not running).

This concept aims at using a second airflow intake when the car is fast-charging to reduce the bottleneck in the front opening. This concept can be used as a complementary solution, including the two previous detailed concepts. Consequently, this section will focus on the secondary system (from the second opening to the cooling pack).

- The AS controlling the front opening stays hidden (behind the spoiler mesh)
- The AS is composed of two arrays of moving vanes. The size of the bumper opening determines the number of vanes.
- The two arrays of vanes are linked behind the central link.

- The activator as in all Volvo projects would lay on the side of the AS to prevent it from damaging the cooling pack in case of a crash (Allianz test).
- The second opening can be done on the fender, under shield or hood of the vehicle, and a passive or active solution regulates the air flow.

7.3.1 Detailed Design

This solution has a tremendous impact on the surrounding systems since the Front Block of the vehicle is already very optimised to take all the system into account.

The detailed design is confidential and therefore, only described in Volvo's version of the master thesis report.

7.3.2 Summary - The Synergy

+	-
Improved Air flow Entry	Increased complexity
Improved air dispersion over the cooling pack	Increased Cost
	Create Packaging conflicts

Table 7.3: Summary of the Synergy

7.4 Discussion

As it has been highlighted in the preceding Sections, the different final alternatives are nevertheless at the level of concepts. They should be further investigated, and especially tested or simulated in order to be able to estimate their Business value.

We have taken inspiration from current commodities which are already on the market, but we should make sure to supplement a part of innovation since we cannot be innovative or have an advantage of "being first" by just looking at what has previously been done. This matter is particularly complex to handle in the automotive market considering the costs-, the weight- and the performance aspects are especially dominant. In this case, it is particularly hard to improve the product without compromising the cost of the system.

Among all those concepts, it can be quite complex to judge specific concept with each other since they aim at different directions for the AS-strategy so the total reflection on the system should be taken into consideration before selecting a unique design.

7.5 Conclusion

Among all the concepts created through the project, the final concepts which have been detailed in this Section are the Classic, the Other, and the Synergy. They have been chosen for their diversity, considering they are three possible directions for the system-strategy (respectively Optimising, Being visible or Focusing on the fast-charging). The previous Section presented further insights and suggestions on their "detailed" design with the material- or manufacturing considerations.

Finally the three concepts are summarised using key words:

- **The Classic**: Conservative - Optimising structure
- **The Other**: Styling - Drag
- **The Synergy**: Innovative - Cooling needs - Complex

8 Discussion

This chapter is a short reflection of elements of the project group has recognised as essential to reflect on and discuss. Therefore the following sections will reflect matters regarding project scope and teamwork.

We had the opportunity to define the scope of our thesis by our-self by contacting experts during an internship in the summer of 2018, and this was an exciting but challenging experience. At the beginning of the master thesis in January 2019, we understood that our scope was nevertheless too broad and re-targeting the project was a necessary action even if it needed significant time and created delays in the remaining parts of the thesis. Making sure that all the stakeholders' and sponsors were aligned was critical before starting the activity.

Looking back at the master thesis project, it can still consider that the thesis had an extensive scope since the HoQ could have fitted to be a complete thesis by itself. It was very challenging to limit the resources on the HoQ to keep our balance with the second section of the thesis, that was the concept generation phase. Consequently, even if we produced solid foundations, the HoQ should still be slightly deepened by including the AL and other stakeholders that we did not take into consideration. Additionally, specific targets for the engineering metrics should be selected in order to be able to analysed the concepts to those defined target specifications.

Moreover, the investigation of innovative concepts could have taken longer than six months since even if all the thoughts utilized by the different OEM are relatively similar, they differ a lot on the specific level.

Our projects results explained that nothing could be done individually; many stakeholders are always inter-related in the thesis assignments, which calls for collaboration as well as close communicating. This communication can take a tremendous amount of time, but it is critical for the task.

Especially in a large company such as Volvo, every employee has a rather well-defined position, and it can become relatively complex and take some time to ascertain the "right" person. On the other hand, this organisation ensures that an expert covers separately area of expertise.

During the master thesis project, we needed some experience to understand who were the experts and who had the information to solve the problem and we highly benefited from the summer internship 2018, to begin establishing a network inside Volvo Cars to facilitate the beginning of the master thesis. Despite it, scattering the expertise amongst departments made the tests and simulations further complex to request and carry out.

A significant component of the master thesis project was turned on the DfSS. Additionally, to the results of the HoQ which have previously been detailed earlier in the Section 5.7, we can highlight that the DfSS tools helped to support collaboration within the design team but likewise between the team and the external stakeholders (such as the AL and function owner). Moreover, the actions described in the GTDS process were beneficial for the outcome of the project to become further familiar with the system studied.

On the other hand, we should not forget that the reality of those guidelines differs from the theory described in academic literature and education. After our discussions with the Quality Engineers, or Quality researchers and "industrial" supervisors or engineers, we concluded that one secret of those quality tools is to be able to modify them depending on the specific context. Furthermore, it could explain the reticence and resistance of the engineers to use the quality tools in their daily tasks.

As mentioned beforehand in the report, we presented the process we used to fill the HoQ to the Hardware Quality Team. This master thesis project was one of the first HoQ done within Volvo and especially the first one practising further than one HoQ matrix, that was the Product Planning and Part Deployment matrices.

During the master thesis project, we have engaged more than thirty different stakeholders through general meetings. We also shared more spontaneous moments with some of them during lunches or diverse fika, and we realized that those more relaxed moments were sometimes the best opportunities to have information or answers to the questions. From a general point of view, all those informal moments were compelling to create social connections with everyone and were sometimes crucial to answer some of our issues or questions or to establish a collaborative atmosphere!

This thesis, like every project, raised the question of transferring knowledge to make sure that the tacit knowledge created will stay as a tacit knowledge within Volvo at the end of our project. First, it is explicit that writing another document won't support considering there are already a considerable number of reports, guidelines inside Volvo, and they are often not read. After some reflections, it was decided that the ideal way of transferring our knowledge would be to share it periodically with the team and this is why we made sure to regularly attend to the Stand-Up meetings to share as much as possible our leanings with the team. Moreover, those interactions were also critical to create transparent communication among us and supported their interest in our project. Those exchanges provided us also the opportunity to get the feeling of the daily life of an agile team and to understand the regular troubles faced by the part.

Last but not least, the teamwork has had a large part in the "success" of our master thesis. The project enabled two different fields (Quality and Product Development) to be taken hand in hand, and this has been possible by creating a synergy of the interests and competencies of the members of the team. At the end of this project, we both learned in both field, and this is was a real opportunity to see how combining complementary domains and competencies creates an authentic synergy in the project.

Another dimension which was vital in our project was to be able to "understand" each other, and this empathy was crucial for preventing conflicts from escalating. It is also essential to communicate with each other to make sure that problems were resolved as quickly as they may appear but also make sure that each member feels listened and respected.

9
Conclusion and Recommendations

This final Section will highlight the main relevant findings and results from this master thesis project as well as concluding remarks.

9.1 Conclusion

This section is the opportunity to answer to the initial research questions presented in Section 1.2; those have guided and focused the master thesis project.

- *What are the differences between the battery electric vehicle and internal combustion engine vehicle requirements?*

As highlighted through the report, the two power-trains have very different cooling needs since the electrical engine is far more energy efficient. The maximum cooling needs for the ICE is at top speed while it is when the BEV is fast-charging - then standing still.

The battery used for the BEV needs to be within a specific range of temperature to the maximise its energy efficiency. Therefore the energy of the battery can be used to warm the engine bay in cold climates to keep the battery cells above the minimal temperature and in order to keep this heat inside the engine bay, the shutters should be closed. And this is goes against the general requirement of letting the AS open in cold climates to prevent it from freezing.

Furthermore, in the case of the BEV, the ICE does not cover the sounds coming from the different mechanisms. Then the sound of all the systems is critical.

- *What are the best concepts of active shutters based on the requirements for the battery electric vehicles?*

This project highlighted that the concepts used for the HEV are nevertheless highly competitive for the BEV. Among the three principal alternatives (the Classic, the Other, and the Synergy), it is accessible to recognise a substantial part of inspiration from the current concept. The final concepts which have been chosen for their diversity are the Classic, the Other, and the Synergy.

- *How is Design for Six Sigma an enabler for cross-functional collaboration?*

The structure provided by the GTDS enabled all the stakeholders to share the same structure and language, to agree on and handshake the deliveries. The different tools integrated into the DfSS methodology, such as the project charter, made sure that the stakeholders were aligned. DfSS also helped to understand the system but also with which other systems it is interacting with. This experience supports collaboration within the Design Team but also with the engineers that are responsible for the interacting systems.

The HoQ supported cross-functional discussions by breaking the boundaries between the stakeholders by gathering them collectively. Moreover, the HoQ included all their needs in the same document, raising the awareness of each other, and they had an opportunity to ask around and understand the needs of each other. DfSS provides a structure which enables everyone to receive the equivalent knowledge and to stay as unbiased as possible.

- *How can iterations loops refine concepts?*

The three iterations used in this master thesis project supported the concepts through their refinements since some of them started the project as conceptual ideas. It needed time to learn new insights and knowledge before generating and screening detailed designs. A quote from a supplier confirms how incremental improvements brought experience rather than having radical changes: *"Our History with Volvo is an Evolution rather than a Revolution"* .

9.2 Recommendations:

In conclusion, our recommendations to Volvo Cars for the further investigations of the AS for the BEV, in order to achieve a greater version of the shutter system, are as follow:

- As mentioned already several times through the report, the concept has not been virtually or physically tested, and this would be critical to verify the hypothesis and to be able to compare the benefits and costs of each solution.
- As mentioned earlier, the profitability of BEV calls for cost reduction while customers are not ready to renounce to the flexibility. A solution to this apparent paradox could be to investigate the potential modularization of the AS to standardize the components that are carried over throughout projects.
- Some recommendations have previously be listed in Section 7, but through the master thesis project, we saw that some OEM have re-building the full cooling system by tilting the cooling pack and Volvo could likewise investigate that.
- During our exchanges with experts in-house as well as suppliers, we think that Volvo should be able to request more simulation and optimization results from its suppliers to be able to increase the knowledge in-house of the limits of individual part and understand the motivations following each design.

- The DfSS tools applied throughout this project supported the team members to grow as engineers, and we would like to advise to other product designers to follow those tools. An HoQ can easily be updated for a separate project to support the communication between the different AL and other stakeholders.

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Appendices

A

DCOV Process

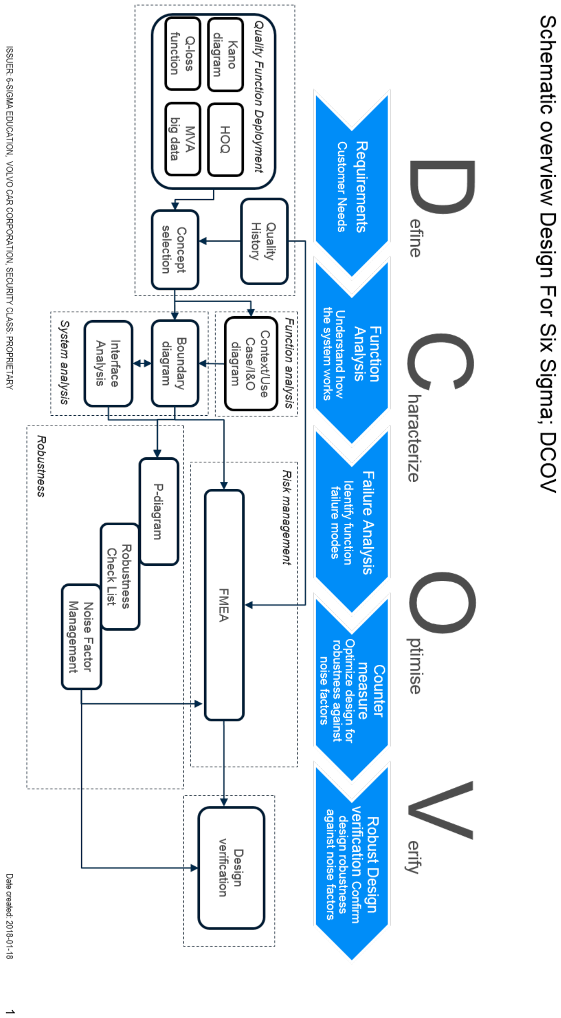
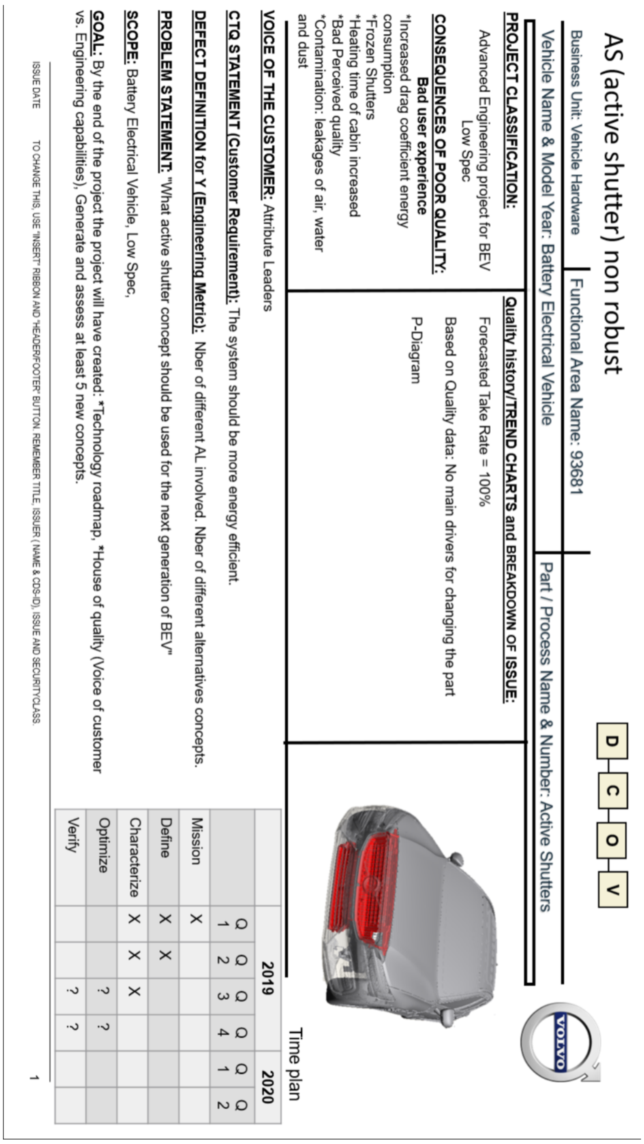


Figure A.1: DCOV Process

B

Project Charter



AS (active shutter) non robust

Business Unit: Vehicle Hardware | Functional Area Name: 93681

Vehicle Name & Model Year: Battery Electrical Vehicle | Part / Process Name & Number: Active Shutters

D – C – O – V

PROJECT CLASSIFICATION:

Advanced Engineering project for BEV Low Spec

CONSEQUENCES OF POOR QUALITY:

Bad user experience

*Increased drag coefficient energy consumption
*Frozen Shutters
*Heating time of cabin increased
*Bad Perceived quality
*Contamination: leakages of air, water and dust

Quality history/TREND CHARTS and BREAKDOWN OF ISSUE:

Forecasted Take Rate = 100%

Based on Quality data: No main drivers for changing the part

P-Diagram

VOICE OF THE CUSTOMER: Attribute Leaders

CTQ STATEMENT (Customer Requirement): The system should be more energy efficient.

DEFECT DEFINITION for Y (Engineering Metric): Nber of different AL involved. Nber of different alternatives concepts.

PROBLEM STATEMENT: "What active shutter concept should be used for the next generation of BEV"

SCOPE: Battery Electrical Vehicle, Low Spec,

GOAL: By the end of the project will have created: *Technology roadmap, *House of quality (Voice of customer vs. Engineering capabilities), Generate and assess at least 5 new concepts.

Time plan

	2019				2020	
	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2
Mission	X					
Define	X	X				
Characterize	X	X	X			
Optimize			?	?		
Verify			?	?		

ISSUE DATE TO CHANGE THIS, USE "INSERT" RIBBON AND "HEADER/FOOTER" BUTTON. REMEMBER TITLE, ISSUER (NAME & CDS-ID), ISSUE AND SECURITYCLASS. 1

Figure B.1: Project Charter

C

Function Tree for Problem Clarification

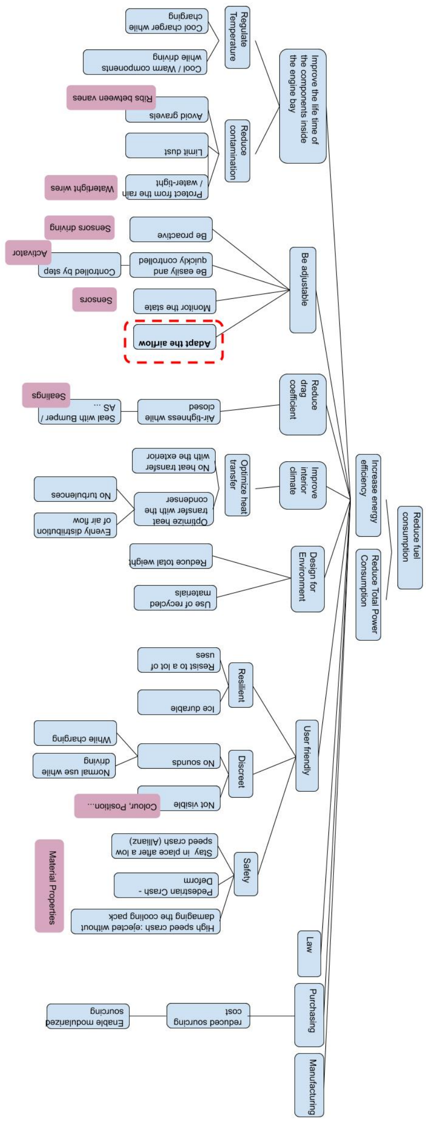


Figure C.1: P-Diagram

D

P-Diagram Problem Clarification

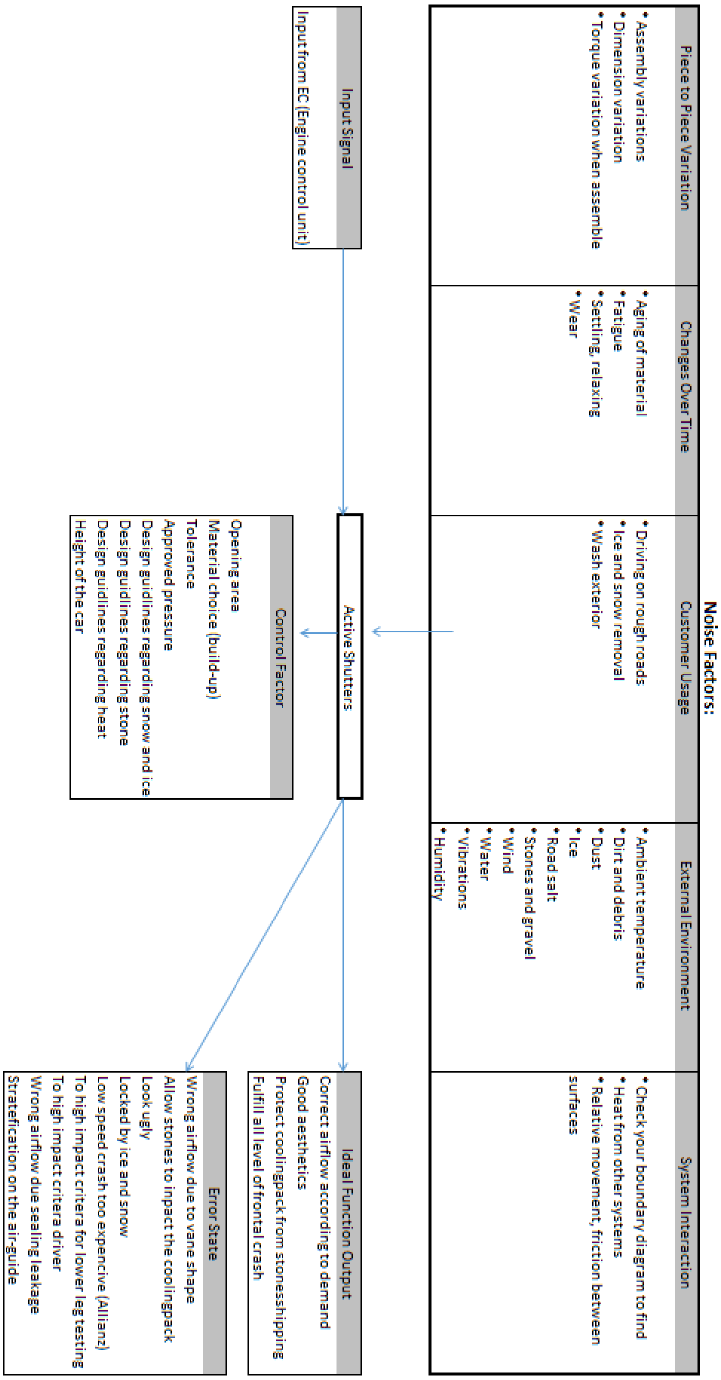


Figure D.1: P-Diagram

E

NFM for Problem Clarification

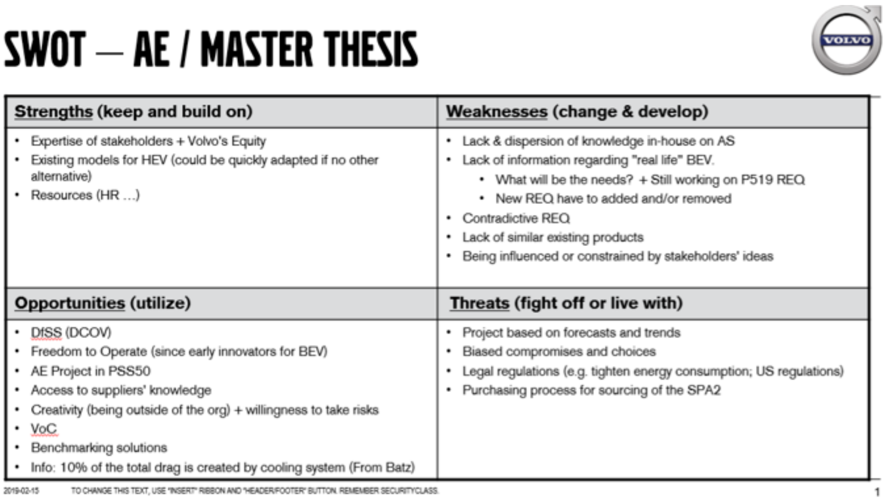
Error States		
Stratification on the air-guide		IX
Wrong airflow due sealing leakage		VIII
To high impact critera driver	High Impact Error State	VII
To high impact critera for lower leg testing	High Impact Error State	VI
Low speed crash too expencive (Allianz)	High Impact Error State	V
Locked by ice and snow		IV
Look ugly		III
Allow stones to inpact the coolingpack		II
Wrong airflow due to vane shape	High Impact Error State	I

Noise 1: Piece to Piece Variation	Metric:	Range:	I	II	III	IV	V	VI	VII	VIII	IX
* Assembly variations	mm				S					S	
* Dimension variation	mm		W		S					W	
* Torque variation when assemble											
Noise 2: Changes Over Time											
* Aging of material					W					W	
* Fatigue	Pa										
* Settling, relaxing										W	
* Wear											
Noise 3: Customer Usage											
* Driving on rough roads	Joule (Hz)										
* Ice and snow removal	Joule		S		W	W					
* Wash exterior	Pa				W	S					
Noise 4: External Environment											
* Ambient temperature	C					S					
* Dirt and debris	mm			S							
* Dust	mm					W				W	
* Ice	mm		W			S				S	
* Road salt	gram/l										
* Stones and gravel	mm		W	S							
* Wind	Pa										
* Water	Pa					S				W	
* Vibrations	Hz		W							W	
* Humidity			S			S				S	
Noise 5: System Interaction											
* Check your boundary diagram to find							S	S			S
* Humidity from the condensor						S					
* Heat from other systems	C					S					
* Relative movement, friction between surfaces	mm		S							W	

Figure E.1: NFM

F

SWOT



SWOT – AE / MASTER THESIS

Strengths (keep and build on)	Weaknesses (change & develop)

• Expertise of stakeholders + Volvo's Equity
• Existing models for HEV (could be quickly adapted if no other alternative)
• Resources (HR …)
	• Lack & dispersion of knowledge in-house on AS
	• Lack of information regarding "real life" BEV.
	  • What will be the needs? + Still working on P519 REQ
	  • New REQ have to added and/or removed
	• Contradictive REQ
	• Lack of similar existing products
	• Being influenced or constrained by stakeholders' ideas

Opportunities (utilize)	**Threats (fight off or live with)**
• DfSS (DCOV) • Freedom to Operate (since early innovators for BEV) • AE Project in PSS50 • Access to suppliers' knowledge • Creativity (being outside of the org) + willingness to take risks • VoC • Benchmarking solutions • Info: 10% of the total drag is created by cooling system (From Batz)	• Project based on forecasts and trends • Biased compromises and choices • Legal regulations (e.g. tighten energy consumption; US regulations) • Purchasing process for sourcing of the SPA2

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Figure F.1: SWOT Analysis of the Project

G

PESTEL

Political Trends	Economical Trends		Societal Trends	
Stricter environmental regulations in all the market	Cost Pressure. Try to share costs with other models & Co? Platform & modularization ?		Flexpool: Change of ownership principle. We rent a car according to the specific uses we have => all the cars are the same and used for very different uses 7/7 + bought by a professional.	BEV- Drive dista e.g. 50% of Volv
Less than 5% of potential buyers ultimately purchase an EV over an ICE model (~4% in the US, ~3% in Germany, and ~22% in Norway – due in part to government subsidies)	Cars sold in emerging countries. Which conditions? e.g. weather? or road quality?		Younger people using cars. More sensitive to noise.	AI raising. Could be used t
Bonus / Malus points. Right to drive certain days only if you are below emission limits	Under the current growth trajectory, EV producers could almost quadruple that achievement by 2020, moving 4.5 million units, around 5 percent of the overall global light-vehicle market. Pure electric vehicles (BEVs) currently make up 66 percent of the global EV market. BEV sales are growing faster than those of plug-in hybrid vehicles (PHEV). The Chinese market expanded by 72 percent over the previous year in 2017, solidifying China's leadership position in EV sales. The		China is leading the EV market https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/dynamics-in-the-global-electric-vehicle-market Based on emissions?	Digitalization

Figure G.1: PESTEL Analysis of the Project