CHALMERS
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Automotive Exterior Films

Elicitation of Stakeholder Needs and Development of Product Specification

PPUX05 - Master's Thesis in Product Development

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

Thin polymer films first came to the automotive market from military aircraft, and have since been used mainly for protection of the car body from mechanical damage. With technology developments, the range of potential applications now involves protection, application of custom graphics and even use instead of paints. Thin films are widely used in automotive aftermarket, as well as by car original equipment manufacturers (OEMs), mainly on interior components. So far their exterior applications have been limited, mainly due to reluctance of the industry and lack of existing knowledge of the product. In order to enable the use of films by the OEMs, these two obstacles need to be addressed.

The first step in introducing a product in the automotive market is to determine its prerequisite specification. Therefore the primary goal of this project is to establish the requirements specification for automotive exterior films as well as compile crucial design guidelines for their application, which should enable the use of polymer films on different parts of a vehicle.

This task was approached by first eliciting the needs of car users and other stakeholders involved in car and film design. These needs were then translated into technical requirements and, basing on industrial practices, assigned proposed target values. The results of the need elicitation yielded a total of 60 different stakeholder needs, which were turned into 77 separate technical requirements. The adaptability of the specification was enabled by the use of numerous attributes to the requirements, such as film type, target area and surface finish.

Additionally, basing on interactions with stakeholders, a set of indirect needs, design guidelines and additional information was obtained, which can be a valuable base of knowledge for further work with exterior films. This project can be continued in various ways, the most important of which is the development of missing test methods for requirements and test validation of proposed target values.

Keywords: Exterior Films, Paint, Vehicle Exterior, Paint Protection Film, Wrapping Films, Coatings, Polymer, Requirements, Specification, Value Driver.

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Vignesh Mohan
&
Jakub Slowinski

Gothenburg, June 2017

Contents

List of Abbreviations

ABS Acrylonitrile butadiene styrene.
ASTM American Society for Testing and Materials.

CEVT China Euro Vehicle Technology AB.

GU Gloss Unit.

HoQ House of Quality.

IPC International Patent Classification.
ISO International Organization for Standardization.

OEM Original Equipment Manufacturer.

PC Polycarbonate.
PESTEL Political, Economic, Social, Technological, Environmental and Legal.
PET Polyethylene terephthalate.
PU Polyurethane.
PVA Polyvinyl alcohol.
PVC Polyvinyl chloride.

QDA Qualitative Data Analysis.
QFD Quality Function Deployment.

R&D Research and Development.

TBD To be decided.
TPO Thermoplastic olefins.
TRL Technology Readiness Level.

UV Ultraviolet.

VOC Volatile Organic Compounds.

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Introduction

Exterior components of a car play a crucial role in establishing its perceived image[1]. The geometric design, colour and the texture are the major factors that ensure that the vehicle is visually appealing to the users. It is also vital that the attractiveness of this appearance is not damaged throughout the use of a car, because of bad weather, scratching or corrosion. This is why since the early years of the automotive industry, various kinds of paints and coatings have been used to cover the vehicle body for most attractive looks.

With technology advancements and increasing demands from the customers, more solutions for car body coating have been developed such as waxes & sealants, clear films and ceramic coatings (Ahmad, 2016). Simple paints were replaced with multi-layered paint-coating systems, and more recently various resins and polymer-based films have been introduced. These films, originating from the aerospace industry, can provide benefits with regards to quick appearance customization, which makes them a desirable product for use by an increasing number of equipment manufacturers in the automotive industry. Such plastic films can have a protective role for the existing paints and coatings, as well as a decorative one, where they could be applied with the paint or as a replacement for the paint to obtain desired visual effects.

1.1 Company background

China Euro Vehicle Technology AB (CEVT) is a part of the Geely Automobile Holdings Limited, which in turn is a subsidy of the Zhejiang Geely Holding Group Co., Ltd. It was founded in 2013 with a primary goal of providing services in the area of Research and Development (R&D) for the brands belonging to Geely Auto and Volvo Cars Corporation. At present, CEVT develops products for the European as well as Chinese markets by catering to various brands such as Volvo Cars, LYNK & CO, and Geely [2]. The company plays a vital role in the development of the following components:

- Architecture Development (Compact Modular Architecture, for instance)
- Development of Top Hat

[1] Marcus Schill; CEVT AB. Personal communication on 2017-03-01.

[2] Source: External CEVT Official Corporate Presentation; Published on 2016-10-26; Accessed on 2017-03-02

- Shared components across various brands
- Total Vehicle Design
- New Technologies and Advanced Engineering

All aspects of design including chassis, powertrain, electrical, electronics, interior and exterior are covered by the company.

1.2 Project Background

While polymer films have been known in the industry for a number of decades now, their use is rather limited to interior components (door panels, console panels etc.) and plastic parts where film application could be automated (Grefenstein and Kaymak, 2003). Therefore the knowledge about exterior films is not common to all major players on the automotive market and applications tend to be conservative. Since CEVT is a relatively new company on the market, it aims to explore the possibility of incorporating the alternatives to traditional paints, such as polymer films. Thus it needs to develop expertise in this field from the design perspective.

Films, similarly to all coatings of a car, and more broadly to all components, need to conform to certain specifications - this way knowledge about the product is utilized in the design process to ensure product quality and functionality. Each of the vehicle exterior parts has different geometrical properties, materials used and functional attributes. Thus, the films that are applied onto such parts should vary in their own properties to enhance, or at least not impair the primary functions of their substrates (base components). Moreover, there are other factors such as cost, quality perceived by the end users, availability of the suppliers, ease of installation of the films by the operators, and many more, which need to be considered when selecting the film for a component. All the above yield certain requirements which the films need to satisfy.

Furthermore, it may occur that the design of the components, the choice of material or manufacturing method may affect the ease, or even the feasibility of film installation to their surfaces. If the scale of the use of films is to be increased, the design guidelines regarding adjustment of components to film application need to be implemented.

1.2.1 Problem statement

The statements above imply that the following problem is to be solved by this thesis project: to establish the requirement specification for vehicle exterior films as well as compile crucial design guidelines for other vehicle components, which could enable easier installation of the films; all with an aim to facilitate the most effective matching of films to the respective areas of car exterior. These specifications are also to facilitate customization so that they can be adapted to use for different exterior components.

1.2.2 Project Scope and limitations

The main aim for the company is to produce the specifications which would be relevant for most types of films used in vehicle exteriors (excluding window films). However, this scope was limited to include mainly hand-applied paint protection films and decorative films (so called: wrapping films), since this branch was found to be not very well explored on the vehicle OEM level. These films were also chosen because the OEM can affect their selection and installation, while other types often lie within the competences of component or sub-system suppliers[3]. Since the company's focus is on the private car segment, commercial vehicles are not considered for this project. The assumed areas of use involve all visible surfaces of the vehicle body; primarily, but not limited to body-coloured components.

The project was defined for the duration of 20 weeks, starting on 30th January 2017. It was performed by a team of two students, both involved in the project in full time. It was also assumed that the authors would be supported by the company with its employees' expertise as well as with logistics related to the project.

The main deliverable of this project is the requirements specification for the exterior films. This specification is to cover all the aspects which may be expected in all areas of the vehicle. A set of guidelines regarding the customization of the specification is also to be included, however this project will not result in the specific list of requirements for films applied on each exterior component - this customization is to be performed later, following the advice in this report.

Furthermore, this specification will only be a preliminary one - several requirements may appear for which not test methods were developed, and for which the target values are unknown. Therefore with increased knowledge based on testing and further research, this specification is to be revised (more precise information can be found in Chapter 8).

Finally, for this project it is assumed that the specification is to be developed primarily for the purpose of purchasing a desired film from the supplier, and not for design and development of the film technology by CEVT itself. Therefore, while the standard methodology for acquiring customer needs is devised (see Chapter 3), these needs are mainly concerning the solution space and selection of films from existing suppliers' product range.

It also needs to be noted that the scope of this thesis does not include the design of testing methods for the requirements. Where possible the existing methods are to be used, and the requirements are not to be verified with regards to their target value within this project.

The full list of deliverables of this project includes:

- Planning report for the project, submitted within the first weeks of the project.
- Initial requirements specification for use of polymer films on car exterior - both as company document and as source file.
- Project report summarizing the progress and the results of the project, includ-

[3]Katrina Chang, Uno Andersson; 3M. Personal communication on 14th February 2017.

ing the specification
- Any other results of a project - prototypes, files containing collected data or data analyses etc.
- Presentation of the project results - performed both at the University as well as in the company.

1.3 Report outline

The main goal of this report is to document the progress and outcomes of the thesis project regarding the development of requirements specifications. It is also aimed that the report is to be used to enhance readers' general knowledge about the automotive films market, so that it can be a basis for further work on the product specification. The intended audience of the report involves both the academic community as well as engineering professionals; the former of these groups likely to have a more holistic and critical view, while the latter aiming mainly to extract the desired data in an efficient way. Therefore the report has to convey a large amount of information in a relatively easy to navigate way, at the same time maintaining maximum of transparency regarding the methods and progress of the project.

In order to achieve this, the project report is structured as follows:

- **Product Context** - providing information on how polymer films are used in the industry and what are the different types of films available.
- **Research Approach** - giving a brief introduction to the approach taken in order to develop the requirements specification.
- **Market analysis** - showing the results of a brief market research conducted on the existing market trends, patents and technological advancements, as part of the data collection process
- **Requirements** - detailing on the process as well as on the results of the stakeholder need elicitation and converting the needs into requirements specification
- **Recommendations** - providing information on other relevant data, increasing knowledge in the field of automotive films, but not strictly related to film specifications
- **Validation and discussion** - describing how the developed requirements were validated, as well as addressing issues which may have affected the project
- **Conclusions** - briefly summing up the performed work and proposing further activities related to the specification

2

Product Context

The use of films in the automotive industry has its roots in the aerospace applications for military purposes. Robust but heavy protection films used on aircraft were re-developed for use in cars and adjusted for the consumer market. (Hodge, 2011). Currently, films used in the automotive industry can be divided in two main categories:

- **Protective Films:** used mainly on the exterior of the car, particularly in areas where the paint on vehicle body is exposed to wear and impact from dirt and gravel from the road. Their main function is to ensure that the paint coating of a component is not damaged throughout its lifetime, and to preserve good quality of appearance over time. They usually have a form of thin transparent sheet covered with an adhesive material on one side (see Figure 2.1(a)). Materials such as Polyurethane (PU) are usually used for production of these films.
- **Decorative Films:** used both in the interior and on the body of a car. They are applied directly onto the component with or without prior painting as desired. They form an opaque or translucent layer to provide the desired colour, pattern or visual effects on the surface of a component (see Figure 2.1(b)). They can be applied to parts of various materials and geometries with various methods. Wrapping films, a form of decorative films, are widely used in the aftermarket for colour and pattern application. Various materials can be used to manufacture such films, depending on intended component material; with PVC or other vinyl compounds for manual installation on large areas, to ABS or PET for in-moulding or other installation integrated into manufacturing of plastic parts.

There are numerous types of films on the market, which may vary greatly in their structure and applications. However, most of the films comprise a few layers of different polymeric materials, as shown in Figure 2.2. The security strip, which is removed prior to installation is followed by an adhesive, which may be applied with a pattern easing the film installation. The adhesive is attached to the coloured core layer (it is transparent in protective films). This layer is covered with a clear coat which ensures protection against scratches and other damages. The thickness of the films may vary depending on the materials used, required colour and protection level.

The main advantage of using polymer decorative films on car exterior is that they

(a) Paint Protective Film

(b) Wrapping film on an upper bumper

Figure 2.1: Types of Exterior Films

allow a quick and fairly cheap change of car appearance. Films of various colours are readily available and several suppliers offer printing of custom graphics on their films, which is particularly valued in the advertising industry and among car fleet owners willing to signify their cars. The protective films cannot be printed with colours or graphics, however they offer superior mechanical properties, especially in terms of scratch and impact resistance. Finally, since they consist of mass-produced polymers, their cost is usually lower than that of paints and protective clear-coats (Mergentime, 2016).

The problems currently faced with exterior films primarily concern the installation process, which, except for some plastic components, requires manual labour. This makes the application of films longer and more costly than that of paints, while also giving a higher risk of variation in the final results[1]. The durability in severe weather conditions is also an aspect of concern in the industry, albeit this is claimed to have improved with new generations of films[2].

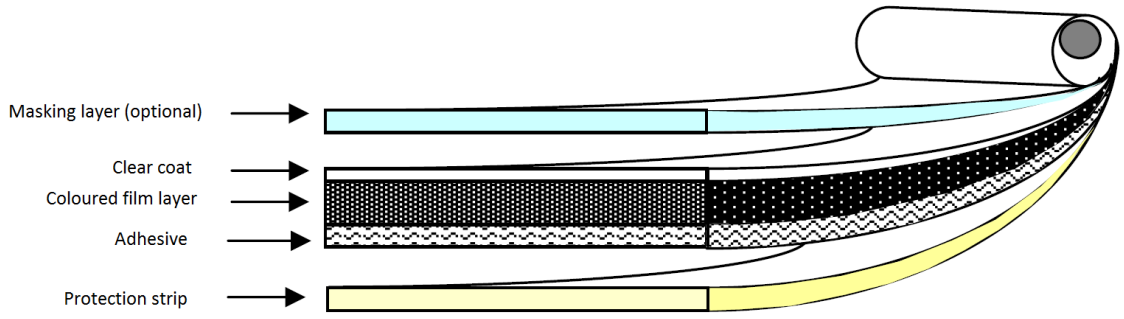

Figure 2.2: Sample structure of an exterior film. Courtesy of 3M.

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[1]Silke Krok-Suhr; CEVT AB. Personal communication on 27th March 2017.
[2]Katrina Chang, Uno Andersson; 3M Svenska AB. Personal communication on 1st June 2017.

There are alternative means of protecting the vehicle exterior. The same level of protection can be achieved through the application of wax/sealants or ceramic coatings. Yet the popularity of such alternatives is relatively lower compared to that of the polymer films in the aftermarket (Ahmad, 2016). One of the main reasons for this is that the quality of these films produced by the market-leading manufacturers is highly commendable, which is further endorsed by the provision of a long warranty period, going up to 10 years (Ahmad, 2016).

2.1 Areas of use

Different kinds of polymer films are currently employed in various parts of the vehicle. Protective films are usually applied to areas prone to impact and scratching during the vehicle use, such as rocker panels, backs of doors, hoods, mirrors etc. They are also applied on the dealership or aftermarket level to other components such as mirrors, bumpers and more.[3]

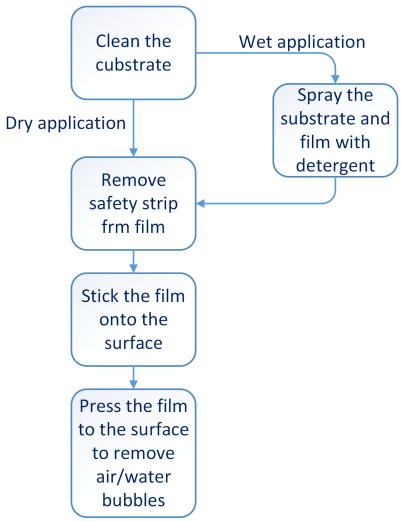


Figure 2.3: Hand-application of exterior films.

Decorative films are used on the car manufacturing level primarily in case of components produced in plastic by extrusion or injection moulding techniques. This allows for the colour to be applied while the component is manufactured thus significantly reducing the cost and time of component production. It also allows to avoid painting the component, which in some cases could prove difficult and thus costly. Such parts include exterior trim components, grilles, some roof panels and some cladding elements.

Less frequently, the films are applied to metal components, where automation of the installation process is more difficult. There are however small areas such as (primarily metal) body pillars and daylight openings, where the use of polymer films is increasing, especially in the low-cost segments of the market.

In the aftermarket decorative films are used for car wrapping, which involves covering the entire vehicle body or its parts with, most frequently, PVC-based film (Mergentime, 2016). The component material is in this case of secondary importance, as the film adheres to the paint coating, which usually has desired surface properties. Hence the film can be installed on practically all body-colour components.

A different type of films, not considered for this project, is so called tint film, used on glass in the vehicle to give it a desired colour shade or reducing the amount of transmitted UV rays.

[3]Katrina Chang, Uno Andersson, 3M Svenska AB; personal communication on 14th February 2017.

2.2 Installation methods

Vehicle exterior films are made of different kinds of polymeric materials such as thermoplastic olefins (TPO), polyurethane (PU), polycarbonate (PC) and more.[1] Because of this, as well as because of the wide range of potential areas of application, there are various methods of coating the components developed by different suppliers. Some of these methods include:

- Manual application - film in rolls or pre-cut to the desired size/shape is supplied to the installation venue, where a trained worker applies it to the given surface by pressing the film to it (see Figure 2.3). There are two main kinds of such application:
  - Dry application - film is applied directly on the cleaned, smooth surface with no prior preparations, and air bubbles are pressed from underneath it by a specific tool. Additional technologies within the film can support this process.
  - Wet application - both the component surface and adhesive side of a film are sprayed with water mixed with mild detergent prior to application. The water droplets are then pressed from between the film and surface with a hand tool. This application is mainly used for transparent protective films[1].
- Assisted manual application - similar to the above, however application process is supported by jigs and fixtures which allow for quick and precise positioning of film relative to the coated component. Mainly used on the car OEM level, where the development of tools specific to given component is possible.
- Automated application - it is mainly used for plastic components, and allows for the film to be applied to it directly in the manufacturing process (see Figure 2.4). Main processes used for this application include thermoforming, co-extrusion, hot stamping and insert molding. (TASUS Corporation, nd) Some suppliers also offer integration of film lamination into roll forming processes. (Soliant LLC, nd)
- Water transfer printing (or hydrographics) - method used to apply printed patterns onto components of various materials: metal, wood, plastic and more. Used mainly for decorative purposes and for vehicle interior applications. The pattern is printed onto film made of PVA, which is spread on water surface in a tank. After treating the film with reacting agent, the component is dipped in the tank so that the film dissolves and the pattern remains stuck to the component. Method is not durable, requires clear-coating for protection (Liquid Print, 2017).

The film can be installed at different stages of the manufacturing and assembly process. Automated methods allow for application during the manufacturing of a component. Decorative hand-applied films can be used on the car assembly stage, usually in the B-shop because of time-consuming manual labour required. Some protection films are applied in transport to the dealers or in the dealership. In the

aftermarket it is also possible to apply both protective and decorative films.

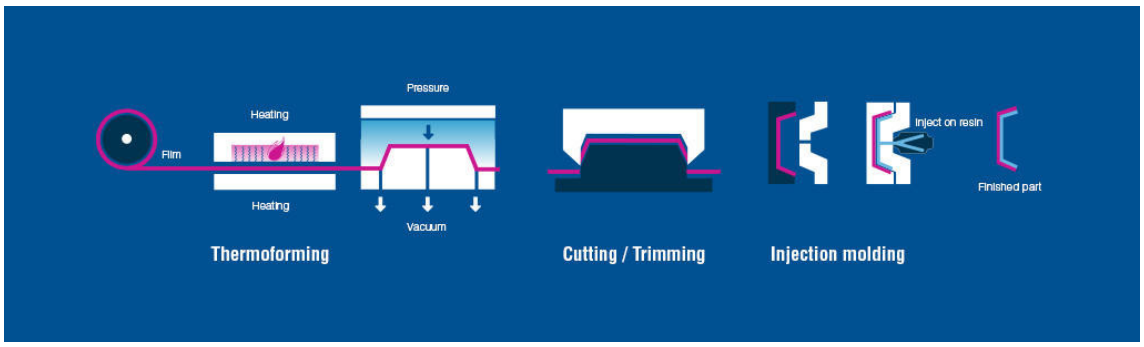


Figure 2.4: Film application in the injection moulding process. Courtesy of Soliant LLC.

2.3 Environmental impact

Polymer films are often advertised as a more sustainable alternative to car painting (Webwire, 2015). However, their exact environmental impact can be more complex to assess. Particularly, the exact comparison to paint systems can be difficult because of wide range of films and paints being available in the market; each comprising different materials and involving different production methods.

Most films and some paint systems primarily involve polymeric materials, which can be assumed to have a similar environmental impact (Baitz et al., 2004). In the installation process (or painting in case of paint systems), polymer films do not cause emissions of volatile organic compounds (VOCs) into the atmosphere, which is considered as their advantage. Use of films also requires significantly smaller resource and energy consumption for installation. However, their installation or preparation for it may involve some waste material. (Baitz et al., 2004).

The waste treatment of films is also largely dependent on the available technologies. A lot of materials included in the film, such as PVC or PU, can be recycled efficiently, however the technologies for this process are still fairly new and may not be common yet (Baitz et al., 2004). Incineration is a viable alternative allowing to recover some of the energy input. However, if the waste is to be land-filled, the environmental impact of the film increases significantly (Baitz et al., 2004).

2.4 Ethical considerations

There are two major ethical issues concerning the use of polymer film in vehicle exterior by the automotive OEM. Firstly, there has been a long-standing tradition for using paints in the industry. Hence the customers may naturally expect their vehicles to be painted, and may not trust other coating methods such as polymer films (Nelson et al., 2016). Considering this uncertain approach, there is an issue of communication of change to the customers. It is important to decide whether the

introduction of films should be announced to the users (since they may not notice the difference themselves), and if so, how this change should be communicated with good results both for the company and its customers.

Another issue concerns the use phase of the vehicle life-cycle. Most of the protective as well as wrapping films allow manual removal, even by an untrained user. This may lead to the user accidentally dislodging the film or removing it intentionally, which can lead to their strong dissatisfaction with the product, or even legal actions against the user, should the film removal alter the appearance of the vehicle. Therefore, measures must be taken, especially with the design of the film installation, to make user's access to the edges of the film as difficult as possible to reduce the risk of the film being removed.

3

Research approach

The success of every product on the market is measured by its sales. In order for the product to achieve high sales, it has to satisfy the needs of the customers and provide the expected value for the money paid for it. Therefore it is essential that the customers are correctly identified and their needs are discovered (Alexander and Beus-Dukic, 2009). These high-level needs then need to be translated into the technical requirements to ensure that the product design clearly reflects or even exceeds the market expectations (Zhang, 2012). This process happens on the following levels:

- High level needs,
- Stakeholder requirements,
- System level requirements,
- Sub-system level requirements,
- Component level requirements. (Hull et al., 2011)

Since this project concerns the lowest level of this structure - component level, the needs on the higher levels need to be collected, as well as specific component-level requirements need to be compiled.

Depending on the nature of the product, requirements may be generated on different stages in the product development process. According to Ulrich and Eppinger (2011), the process of need elicitation and requirement generation form a part of the concept development phase, as shown in Figure 3.1. Hull et al. (2011) adds that the generation of requirements on various sub-system and component levels may take place in later phases of the process as well. This view is supported by Almefelt (2005) who claims that requirements may be generated and carefully managed later in the process in case of innovative products with high levels of uncertainty involved.

There are several processes for developing the requirement specifications, however most of them are derived from the standard procedure involving:

1. Raw data collection on customer expectations,
2. Data analysis, need statements generation,
3. Sorting and prioritization of needs,
4. Technical criteria identification,
5. Definition of acceptance levels. (Ulrich and Eppinger, 2011)

It is assumed that the general approach to the project should embody this established process. However, this methodology needs to be adjusted to the circumstances of the specific industry in which the project is carried out - in this case the automotive

industry.

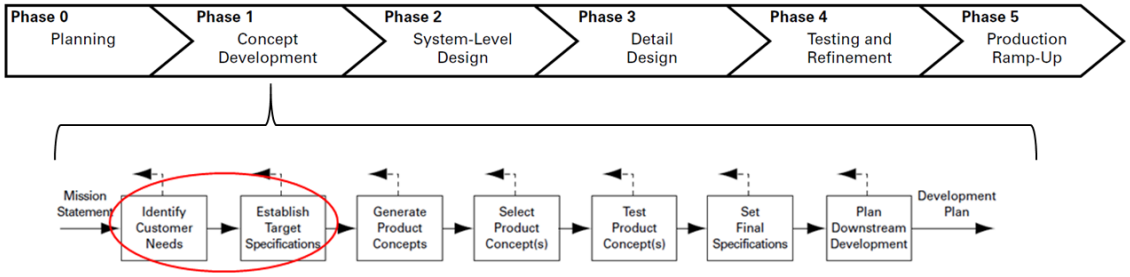


Figure 3.1: Conventional product development process. Adapted from: Ulrich and Eppinger (2011)

An important feature of this industry is that the nature of changes of the products being offered is rather incremental, because of long development cycles for major projects and fairly long-standing industrial traditions. These long cycles and often long presence of some major players on the market (reaching up to several decades) have led to the requirement specifications being based primarily on benchmarks and internal experiences of vehicle manufacturers and the requirement elicitation directly from stakeholders, has been drastically limited.[1]

Therefore, particularly in the data collection phase, it is essential to take into consideration both the customer needs gathered directly from the users and other stakeholders, as well as the internal knowledge of the industry stored in various standards and regulatory documents, to account of the full range of available sources.

It is also vital to maintain the procedure for needs elicitation as transparent as possible in order to ensure the traceability of all resulting requirements (Hull et al., 2011), as well as to allow drawing further conclusions from the gathered data.

3.1 Process structure

It was observed that the majority of the methodologies for requirement elicitation aim at defining problems which are to be solved by the product, without specifying the product itself (i.e. the requirements are solution-neutral); searching for requirements in the problem domain (Hull et al., 2011). Hence a lot of elaborate processes are developed in order to look for deficits and potential areas of improvement (Ronneberger et al., 2013). However, the main goal of this project should be to improve the characteristics of the vehicle where the means (in form of paints and films) are all known and hence the requirements are to be elicited in the solution domain - specific to the defined technology.

As advised by Alexander and Beus-Dukic (2009), for this type of activity, where the focus is on selecting between several product alternatives, the key is to identify the

[1] Johan Torgnysson; CEVT AB. Personal communication on 6th March 2017.

stakeholders and their main goals. It is also essential to explore the technical field cautiously to identify the factors which may be specific to the chosen technology, and not regarded otherwise.

Considering all the above, as well as the fact that this report is also to provide generic knowledge in the field of automotive films, the process flow for this project was established, as shown in Figure 3.2.

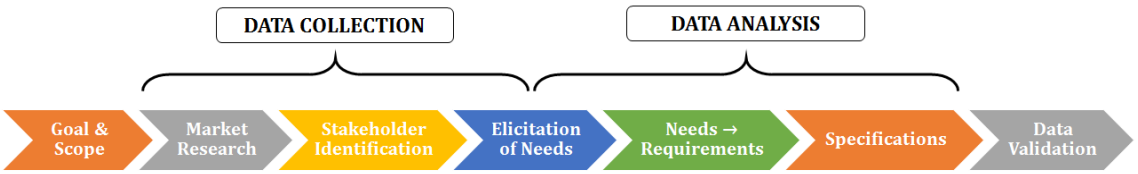


Figure 3.2: Adapted process flow for requirements generation in this project.

The established process uses the general guidelines proposed by Ulrich and Eppinger (2011) and incorporates elements of a softer approach by Alexander and Beus-Dukic (2009) who emphasizes the recognition of context and stakeholders before actual need elicitation. A more detail sequence of actions within this project is defined as follows:

1. Define goal and scope the of the specification,
2. Collect raw data
   (a) Carry out market research to gain general knowledge about the product and trends in the industry.
   (b) Identify the main stakeholders, both internal and external
   (c) Contact the stakeholders to collect their needs
3. Interpret the collected data and compile the list of needs,
4. Sort and rate the needs,
5. Assign technical requirements to the needs,
6. Find the metrics for each technical requirement,
7. Determine the test method and target value for each technical requirement,
8. Assign relevant attributes to the requirements,
9. Validate the collected data

Details of all the actions described above, as well as specific methods and tools devised throughout the process are described in Chapters 4 and 5.

4

Market assessment

The scope of the project touches two industries which only partly interact with each other - the automotive industry and polymer film market. Polymer films first found their application in cars in the end of 1970s (more details in Section 4.4). Since then, both the supply and demand for such films has grown considerably and expanded to serve multiple market segments. A market assessment has been carried out in order to understand both types of products involved (vehicles and polymer films), and to discover how the structure and trends in both of these industries can affect the needs regarding the products.

4.1 Method

Market assessment was based on the analysis of secondary data; mainly widely available business reports and branch articles, as well as general news reports which may have an impact in either automotive or polymer field. Aspects of particular attention involved the demand drivers, market segmentation and current industry trends, as well as historical developments of the technologies.

A wide variety of sources was found and processed, with different scope and depth of content. While the credibility of such choice of sources may prove insufficient for an in-depth analysis of the market, the main goal of this activity was to obtain a broad overview of key points within the industry, and for this purpose the choice of a variety of sources proved more successful than a narrow selection of highly relevant ones.

4.2 Market Overview

The demand for exterior films is fully controlled by the situation in the automotive industry (Plastics Today, 2014), and hence the automotive market will be the primary focus of the assessment. The demand for cars generally originates from the need for both personal and commercial transportation. In the market chain the exterior film is treated on the same level as paint - not as a separate component but as a commodity which is supplied either to the tier component suppliers or directly to the car OEM where it is applied. (see: Fig. 4.1). The films are also supplied to the dealers and aftermarket service providers where they can be used to alter the

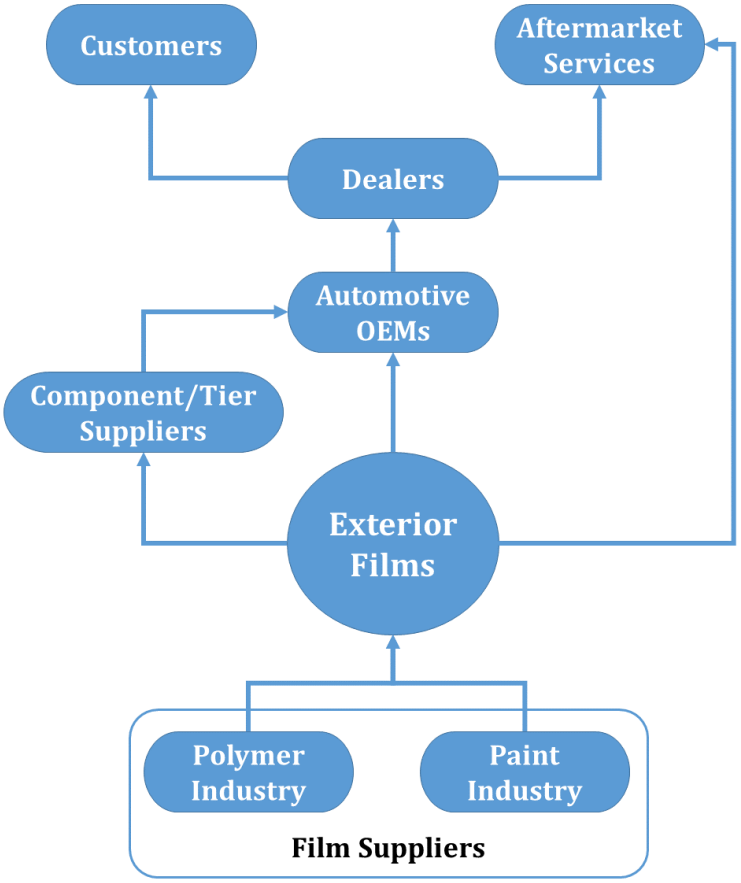


Figure 4.1: Diagram showing supply chain of automotive films.

appearance of a ready vehicle.

The automotive film market comprises a few major segments basing primarily on the installation method of the film, as described in Section 2.2. These segments are partly competing with each other - the films enabling installation early in the manufacturing process (co-extrusion, hydrographics, etc.) can sometimes be used interchangeably. The hand-applied films form an independent segment and do not compete with the former, as currently their main focus lies in the aftermarket (Mergentime, 2016).

The exterior films are to be used primarily on the cars of the Lynk & Co. brand. It was found that the target market for this brand is formed by people living in large so called "mega-cities" and feeling comfortable with the open, urban lifestyle. The reach of the brand is planned to be global, with a main focus on younger people following closely the developments in technologies[1].

[1]Andreas Kåreby, Geely Design. Personal communication on 3rd April 2017.

4.2.1 Suppliers and competitors

There are two main sources of films for automotive applications - chemical/polymer producers and paint manufacturers. While sometimes these two branches may be competing with each other, in most cases they form two divisions of broader chemical industry with the same companies having departments concerning films and paints. Key film suppliers together with a general description of their area of business are presented in Table 4.1.

Table 4.1: Major film suppliers for automotive industry.

Name	Description
3M	Protective and decorative, largely hand-applied (except for Exterior Trim Films)
Soliant / AkzoNobel	Mainly decorative for insert moulding and hot stamping, roll forming
SABIC	Protective and decorative, resins and thick sheets for co-extrusion, in-moulding
Kurz	Mainly decorative, for hot stamping, in-moulding
Avery Dennisson	Protective and decorative for co-extrusion, in-moulding
Xpel	Mainly protective, hand-applied, largely for aftermarket
STEK	Mainly protective, hand-applied, largely for aftermarket
KPMF	Mainly decorative, hand-applied, protective and advertising as well.
TESA	Tapes; foils for temporary protection; adhesives of various kinds

There are several ways in which the films can be supplied to the OEM, depending on their function and installation method. The hand-applied films can be supplied either in rolls or as thin foil sheets cut to the desired geometry, straight to the OEM or component manufacturer where they are installed[2]. Such solution mainly applies to metal components. In case of plastic parts, the film together with machinery for automated application is purchased by the plastic component manufacturer. This solution yields higher initial cost because of the need to additionally equip the in-molding production line with laminating apparatus. However solutions of this type can also be applied to roll-formed sheet metal components (Soliant LLC, nd). The former case offers more simplicity in the supply chain and the latter yield higher productivity because of automation of production.

The total number of companies involved in developing films has been growing constantly since the films appeared on the market (see Section 4.4). However, the number of main players supplying to the automotive industry has remained fairly unchanged, with more innovative ventures being acquired by the larger companies (SpecialChem , 2002). Hence the competition level among the film suppliers remains relatively constant.

Competitors to CEVT (other automotive OEMs) are known to have used the exterior films in certain areas, which mainly include plastic parts. One such area involves

[2]Katrina Chang, Uno Andersson; 3M Svenska AB. Personal communication on 14th February 2017.

roofs, where plastic-laminated roof panels have been used first by Opel in 2007 (Focus on Pigments, 2005). Patterned films have also been used on the roofs of Mini [3]. Mercedes is known to have used the films in the trim components for its A and C-class (Destefani, 2009). Volvo as well as other OEMs have also used protective films in areas such as rocker panels and lower door moulds. Hand-applied decorative films were applied to places such as A and B pillars on the car body by brands such as Volvo.[3]

It was also found that OEMs such as Mitsubishi, Daimler, Toyota and Nissan have put a considerable effort in development of technologies related to films and their application. However, due to scarcity of available data from the film suppliers and CEVT competitors, preparation of the full benchmark was proven impossible.

4.3 Growth projections and trends

The automotive industry appears to slowly recover from the effects of the financial crisis of the early 2010s. The sales grow significantly in the US and remain relatively unchanged in Europe (Armstrong, 2015). In the long term, automobile sales are projected to grown by around 2% per annum, according to Mohr et al. (2016). The growth is projected to be positive despite the emerging changes in mobility patterns which will be further described below. The demand in the automotive industry depends primarily on the economical conditions of the consumers, social changes and technological developments, which in turn are driven by the combination of the above as well as changes in legal policies etc. (TechFunc, 2012). It is widely believed that the industry faces a major shift both in terms of the business models and technologies. The following main trends have been identified to affect the automotive industry in the near future:

- **Change in mobility and ownership patterns:** Increased urbanization worldwide as well as social changes prioritizing environmental behaviour cause the change in the way in which personal transport is viewed. Car ownership is slowly losing popularity to other means of using vehicles such as leasing, car-pool, or car-sharing. The users are less willing to cover the running costs of car maintenance and the additional effort coming with it. The availability of the vehicle has, especially among younger users, become more attractive than owning a car - according to KPMG International (2017), 59% of automotive executives and 35% of surveyed users think that within 10 years car ownership will be reduced by as much as 50%. This implies a move towards a more circular economy, where a vehicle could be owned, re-manufactured and re-distributed in different market segments by the OEMs, while it would not be permanently sold to a user. (Mohr et al., 2016; PwC, 2016). Additionally the tendency towards more direct contact between an OEM and a customer is observed. While dealerships still play an important role in the market it is projected that more brands will operate with altered, more consumer-friendly distribution schemes. (Augustine and Nava, 2016)

[3] Anders Bergstrom; Geely Design. Personal communication on 14th February 2017.

- **Alternative forms of powertrain:** Cost of purchase and operation are still of major concern to the customers. And increasing importance is also the environmental impact of a vehicle. These reasons prompt an increased interest in fuel efficiency as well as in hybrid and electric car powertrain forms. While the demand for electrically propelled vehicles will vary in different parts of the world in the coming years, with their prices decreasing and range improving they are projected to form a significant part of the market (PwC, 2016). This shows increasing interest in reducing the cost of car usage through decreased energy consumption.
- **Stringent environmental norms:** Following the general trends in the societies around the world, as well as attempting to respond to the climate change, the regulators and policy makers around the world tend to put increasingly demanding requirements on environmental aspects of the products. These aspects include emissions, fuel efficiency, recyclability, CO_2 and energy footprints etc. These demands prompt changes in the designs as well as developments of the technologies and further promote use of lightweight solutions for all major systems of a vehicle (PwC, 2016).

The plastic film market is projected to experience a more significant growth over the coming years, reaching up to 5-6% per year This is only partly due to developments in the automotive industry, and to a larger extent an increased demand from the packaging and electronics industries. (Smithers Rapra, 2014). In the particular case of protective films, the main drivers for growth in the coming years include automotive industry, especially in the aftermarket, and aerospace market. A small, but growing share will also be taken by the electronics industry (Grand View Research, 2016). This shows that the position of film suppliers may be fairly strong in contact with a car OEM, and such suppliers may be demanding to negotiate with, depending on the contract parameters.

Within the automotive hand-applied film market, the aftermarket products play a major role and this branch is expected to grow at least until year 2025 (Mergentime, 2016). However an increased activity of film manufacturers can be observed in developing products for use by automotive OEMs. It can be argued that the polymer film industry is planning to expand it's offer to suit the OEM needs in the future[4].

4.4 Patent analysis

Supplementary to the analysis of commercial secondary sources, a patent analysis was carried out to assess the current developments in the technology of decorative and protective films, as well as supporting fields (tooling, adhesives etc). It is aimed that this knowledge can help with assessing the feasibility of current customers' needs as well as provide information with regards to areas worth exploring by CEVT.

[4]Katrina Chang, 3M Svenska AB. Personal communication on 8th May 2017.

4.4.1 Method

The analysis of patents was decided as a fairly reliable source of information on the current as well as historical inventions in a given industry. The studied market segment for this analysis is defined as films for automotive applications as well as tools for their production and application. It is believed that the analysis can allow to observe trends in the industry, define specialist companies and support the segmentation of market.

The analysis was based on a series of searches to form the following sequence:

1. General search to define most applicable IPC classes and most relevant keywords
2. Several searches aimed to direct the results in a correct industry (i.e. towards automotive, not marine applications)
3. Refined search using the keyword combinations and classes defined in previous searches, to limit number of results
4. Export of search results and manual elimination of irrelevant records.

Since the analysis aimed to obtain the technology landscape, it mainly concerned statistical data and consisted of the following steps:

- Browse through the results seeking for patterns within their subject i.e. groups representing market segments, different technologies etc (by patent title and/or abstract).
- Determine the intensity of patent activity over time - patents of each group were sorted with respect to their year of publication to observe numbers of patents published per year across the entire spectrum
- Find a number of patents issued in each of the countries in the result list (from publication number)
- Examine a total number of patents filed by each of the assignees

4.4.2 Technology developments

The search yielded a total of 449 results and the final number of patents after elimination of irrelevant search results reached 187 records. Basing on the search, several general categories of patented products/processes were found:

- **Protective films** - used on the body of a car, but also on wheels, sunroofs etc. They can be divided into: permanent films applied for the use of a vehicle to protect against UV, wear, impact and other environmental aspects; and temporary films applied after coating the component with paint/other coats, to protect the paint job from damage in further manufacturing and assembly process. Total number of patents in category: 70.
- **Decorative films** - involve all films which are designed to change the appearance of the covered surface. Main groups in this category include opaque films aiming to change colour of the surface, and both opaque and tinted/translucent films which can be printed with a specific pattern or graphic design, or give another kind of optical effect. Total number of patents in category: 30

- **Other films** - this category includes films which can have both the protective and decorative application, as well as those where purpose was not defined or cannot be deduced from the patent. In this group there are also patents relating to development of raw materials for films or single layers of films (adhesives, colouring agents etc). Finally a sub-group is formed by films having special features, in this case mainly working as solar cells applied on the car roof or sunroof. Total number of patents in category: 59
- **Tools and methods** - this group gathers all patents relating to hand tools as well as automated apparatus for application of films of different kinds. These patents also disclose methods of film application or removal. Total number of patents in category: 28

Such division of patents clearly shows that the main focus of the industry is in the material science, and, among more specific applications, in protective films.

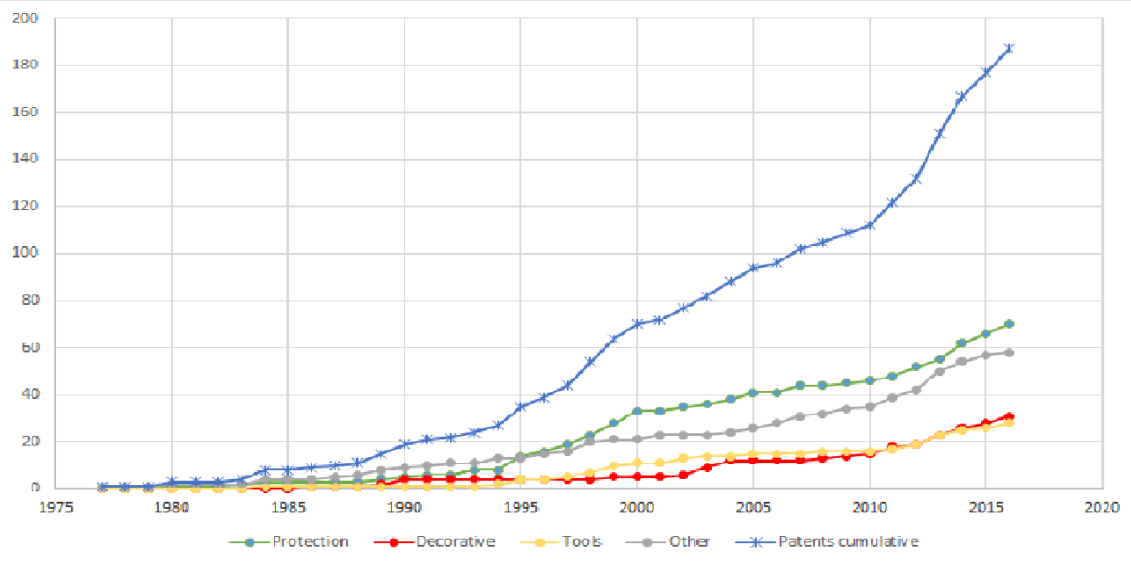


Figure 4.2: Cumulative number of patents issued overall and in each of the analyzed categories over time.

The earliest patents relating to films in automotive applications date back to 1977 which confirms the statement that they evolved from the use of aircraft films in military applications in conflicts of 1960s (Hodge, 2011). As apparent in Figure 4.2 a steady growth in more general film patents ('other' category) was first followed by a rapid development of protection film patents in the 1990s. Similar pattern is visible in the early 2000s where an increase in activity regarding protective films is even sharper. Basing on the results obtained for years 2015 and 2016 it can be stated that this increase in activity is not about to slow down in the following couple of years.

A different pattern is observable in case of decorative films. The first surge of development activity in this area came later than in case of protective films, and a significant increase can be seen in the most recent years. At present, decorative films observe the most rapid increase in activity from all the determined categories. This

shows that the demand for these films is growing and is met with a lot of innovation in the industry. The delay in developments in decorative films may suggest lower priority of this type until recent years. The total activity within this branch is however still significantly slower than for other types. The delayed and smaller activity together can also imply that the film manufacturers re-use the technologies between various types of products, with lower focus on the decorative side.

The activity of research in other films and basic materials is apparent to precede the developments in more specific areas. In recent this area is seen to be developing faster than other market segments, partly because of recent advancements in material engineering, and partly because of new purposes of film applications, such as use of solar power or electro-luminosity. The behaviour of the *Tools and methods* group is more stable than the groups above, partly because of the application of tools to all kinds of films on the market. The increase in recent years is probably a result of more innovations in development of film materials.

Technology Maturity

With over 40 years of presence on the market and use both by automotive OEMs and in the aftermarket, it can be stated that paint protection films are a mature technology with technology readiness level (TRL) of 9 (in a 1-9 scale where 1 denotes development of basic principles and 9 indicates a fully operational technology). (European Commission, 2015). This means that it can be safely used on industrial scale, however certain minor problems with the technology may still exist.

In case of decorative films, the maturity levels vary depending on the requirements. These films have successfully been used in the aftermarket for a number of years (KPMF USA, 2016), thus resulting in a TRL of 9. However among automotive OEMs, who raise questions about the durability of these films and have only used it on smaller areas of the vehicle, the readiness is lowered to a level 8.

4.4.3 Assignees

Throughout the entire period when film-related patents were filed, most applicants have only filed one patent relating to the automotive films (87 out of 118 assignees have only one patent). It is also very rare that a given company has issued more than one automotive-related patent per year. This shows that the automotive industry is only a part of operations for the films market and that films are rarely a subject of a large-scale development effort. Even though this area appears to be developing, it is not in the main focus for either automotive or film industry.

Four out of five companies with the largest number of patents belong to the paint or chemical industry (3M, Kansai Paint, Nitto Denko, Rexam). These two industries appear to overlap as corporations file for patents with their film and paint divisions separately. However the most active player in the market is an automotive corporation - Mitsubishi with 10 published patents. Most of these (7 patents) relate to the protection films. 3M appears to focus its activity on decorative films with a

highest number of 3 patents in this field. In other categories none of the companies has issued more than two patents in the relevant field. There are a total of 10 automotive OEMs who have their inventions in the area of films. Most of their focus is in protection and decorative films, however there is also a significant activity in developing tools and other apparatus for film application.

Chinese and Japanese companies appear to dominate the film market. They have also been some of the first players on it (oldest publications). Other international corporations also appear to publish their inventions in these two countries. Therefore these seem to have the most patent activity, with 60 patents published in China and 64 in Japan. Other significant players involve USA (21 patents), mainly because of activity of 3M, and Germany (13 patents) with activities from automotive industry. None of other countries in the list has more than 2 relevant patents published. This means easier access to cutting edge technologies for automotive OEMs manufacturing in east Asia, such as CEVT, or more broadly, Geely Group.

There is a number of general conclusions which can be drawn from the patent search: the most important being that the R&D activity in the polymer film industry is growing, and hence the introduction of improved and innovative solutions can be expected in the near future. In terms of requirement specification this means the need for incorporating flexibility to accommodate future products which may propose features currently unavailable or poorly addressed. At the same time the general activity in the field reaches almost 30 years back and the most recent surge has already started nearly a decade ago, which shows that the current solutions are fairly mature and safe to use on a commercial scale. Finally it must be emphasized that the area of tooling and automation development in terms of films is fairly poorly explored, which leaves a gap to be filled. The automotive OEMs appear to be interested in the area and the bespoke film installation systems can be the unique know-how of each OEM.

4.5 Data analysis

The main means by which secondary data was analyzed was the PESTEL analysis. This method served to compile the gathered information into topics, which may reveal some market trends and show areas potentially affecting the future needs. In this method, PESTEL is an acronym denoting each of those topics: Political, Economic, Social, Technological, Environmental, and Legal aspects (Malmqvist, 2015). The results of the analysis are shown in Table 4.2 and contain data described in the sections above, as well as general economic and social information, which may impact the area of polymer films, or automotive market in any way.

Table 4.2: PESTEL Analysis

POLITICAL	ECONOMIC
• Isolationist tendency in the US can affect sales of brands not manufactured there (KPMG International, 2017) • The fuel efficiency norms in the European Union are going to be more stringent according to yearly targets – growing incentive for lightweight solutions (KPMG International, 2017) • China is likely to adopt the EU norms • Uncertainty in the political scene in Europe over elections and Brexit – unclear investment directions (KPMG International, 2017) • International deals can affect oil prices, thus car demand (Armstrong, 2015)	• Oil prices can affect the demand (Armstrong, 2015) • Change in the price of commodity goods are likely to affect the overall costs (Armstrong, 2015) • Plastic Film market is developing rapidly; this can have a significant influence on the price of the films • Increase of use of wrapping films in advertising and on fleet cars makes them more accessible • Growing need for affordable cars in the developing economies • New business models – trend towards more direct sales from OEMs, giving higher offer flexibility
SOCIAL	**TECHNOLOGICAL**
• Changing car ownership preferences – lease and car sharing more popular; people not willing to look after their cars (KPMG International, 2017) • Increased awareness of environmental issues – incentive for OEMs to pay attention to their footprint • Push towards customization – need to adapt the appearance quickly and cheaply • Scandals in the automotive industry may discourage people from owning a car and undermine trust to OEMs • Car appearance showing owner's prestige	• Technical advancements in the use of recyclable plastics – incentive to use them in cars • Increasing trend has been observed in the development of films, from the patents – opportunity for better or cheaper films • Technological improvements in Painting techniques may prove films unnecessary • Film technology is mature enough to be used in cars, in terms of Technology Readiness Level (TRL) • Aim towards development of cars that are light in weight and fuel-efficient
ENVIRONMENTAL	**LEGAL**
• Drive towards a clean and green environment in the automotive industry • Need for increased recyclability and/or reusability • Target towards reducing the emissions of vehicles • Trends pointing to wiser usage of resources • Risks of VOC emissions in the painting process	• Labour laws that vary across countries thus affecting manufacturing costs • Stringent Health and safety standards • Adherence to several local as well as global homologation norm • Regulations enforce the use of well tested solutions

5

Requirements development

This chapter details the process of obtaining the requirements based on market analysis presented in Chapter 4 as well as, above all, collected data from interviews and discussions. For the sake of clarity, a *need* denotes desired aspects of the product as stated by the stakeholders, whereas *a requirement* denotes a technical or design feature of a product which is related to the need (Zhang, 2012).

5.1 Goal and Scope

Based on the input gathered from Alexander and Beus-Dukic (2009) and referring to the general project goal and scope presented in Section 1.2, the specific goal was defined for the requirements development process. The developed specification has to serve as means to select the film of the right parameters, adjusted to the desired application area and context.

The scope involves a general case specification for all kinds of films used on vehicles for personal transport. It shall allow use of only selected requirements for specific application cases. It is assumed that the specification will consider mainly hand-applied films, however most requirements may also be applicable to other types. Also, since the specification is thought of as initial, not all manufacturing-related factors are presented, as they may be specifically dependent on assembly plant.

5.2 Stakeholders

A basic step in finding the product needs is to determine the stakeholders who may have some interest in exterior films, by manufacturing them, using them or competing with them. The defined stakeholders are presented in Table 5.1 and all the groups are briefly described below:

Internal stakeholders denote different departments within CEVT and other Geely Group companies, involved in the vehicle design. They are expected to voice different requirements regarding the body of a vehicle in general, or the exterior films in particular. Their requirements may extend beyond those of casual users and involve more technical or business-oriented issues

External stakeholders: involve all groups from outside the company, including

the final users of a vehicle, aftermarket services etc. The requirements of this group are expected to concern later phases of the product life cycle, focusing on use, maintenance and disposal.

Table 5.1: List of stakeholders

STAKEHOLDER	Description	Contacted?
EXTERNAL		
Film Suppliers	Companies manufacturing and selling polymer films	Yes
Tool Suppliers	Suppliers of machinery assisting with film installation	No
Car owners	End users of the vehicles and thus the films covering them	Yes
Film Disposal	Companies responsible for disposal and/or recycling of polymer films	No
Non-users	All stakeholders, both internal and external, who have raised concerns or criticism about the use of films	Yes
Aftermarket services	Businesses installing polymer films on used, private and commercial cars	Yes
INTERNAL		
Component Design	Teams responsible for development of given vehicle subsystems	Yes
Testing	Responsible for design and execution of test procedures	No
Manufacturing Engineering	Responsible for manufacturing and assembly aspects of vehicle	Yes
Styling Team	Responsible for designing the appearance of a car	Yes
Paint Technology	Working with development of new techniques to coat vehicle exterior	Yes
Marketing	Defining high-level goals and target markets for product	Yes
Perceived Quality	Responsible for assessment of design and execution of visual and tactile experience	Yes

Some of the contacted were not contacted, as apparent in Table 5.1. This was either they could not be reached or their area of interest was beyond the scope of this project. All other stakeholders were contacted for either individual or group interviews, as described below.

5.3 Intended film application areas

Basing on the information described in Section 2.1 as well as the data collected from the Styling team, responsible for the appearance design for the vehicle, the desired areas for film installation were determined. It was found that in the longer perspective, the use of films can be considered on all exterior elements, both body-coloured and of additional colours. Nevertheless, there are several areas which are found to have a higher priority for shorter perspective[1] [2].

[1] Anders Bergstrom, Geely Design. Personal communication on 14th February 2017

[2] Henrik Bechtel, CEVT AB. Personal communication on 3rd May 2017.

These priorities were verified by a short survey which was sent to members of 3 departments of CEVT - bumpers/claddings, styling and manufacturing. The survey stated two questions: what areas of a vehicle should be prioritized for film application, and what main function should the film have on the prioritized component (colour, pattern, protection etc). The results (albeit collected from a small number of respondents), have shown the following ranking of prioritized areas and desired functions (where number 1 denotes highest priority):

1. Roof panels - coloured/patterned film
2. Hood - coloured/patterned film
3. Panels in the back of the vehicle - coloured film
4. Bumpers - protective film, coloured film
5. Trim elements - textured/tinted film
6. Mirrors - protective film, coloured film

It was found that there is a particular interest in using polymer films in so called two-tone car colours, i.e. where some parts of the vehicle body have a different colour. In such cases the use of films could eliminate the need for the vehicle to go through the painting process twice, thus potentially reducing the time and cost of painting [3]. Hence, when developing the specification, it should allow adapting to the areas mentioned above.

5.4 Primary data collection

In order to collect the maximum amount of information regarding the needs of various stakeholders, as well as other context information, several methods of data collection were devised. These are briefly described in the paragraphs below.

Semi-structured interviews: formed a major part of the study, above all to obtain knowledge from domain experts and internal stakeholders. They were conducted following the guidelines of McQuarrie (2016), wherein the objectives and preliminary list of questions were developed before each interview. The interviews were mainly conducted in the designated conference rooms and, whenever the technical abilities permitted and interviewee agreed, the audio was recorded.

The main goal of performing the interviews was to identify the specific problems, which the representatives of given fields could face with introduction of polymer films, as well as the opportunities which such introduction could bring. Specific needs regarding the films were also collected from each of the interviewees. A total of 9 individual interviews were carried out with representatives of most of the identified stakeholder groups (see Table 5.1).

The meetings were scheduled to last 30 - 60 minutes. Each interview involved introduction of the project, followed by a few questions regarding the interviewee's background in the field of films and automotive industry in general. These were followed by more specific questions related to each participant's area of expertise. The semi-structured nature of the interviews allowed to ask unplanned follow-up

[3] Silke Krook-Suhr, CEVT AB. Personal communication on 28th March 2017.

questions and change the way of discussion if applicable.

In each meeting two interviewers were present, one of whom focused on the actual interviewing process, and the other took notes of the most important statements. Whenever audio recording couldn't be made from an interview (2 cases out of 9), the data was extracted from these notes. All other talks were transcribed from an audio file afterwards.

Focus groups: A total of 2 focus group meetings were conducted throughout the data collection phase.

- The first meeting, involving 9 participants, focused on discussion of engineering goals and needs concerning the films. The participants represented internal stakeholders at CEVT.
- The second group was formed of car users, and the discussion involved their main needs and concerns regarding the use of films on their car exterior. The participants of this discussion included mostly people under 30 years old, and living in Gothenburg, Sweden, thus reflecting reasonably well the target market the the Lynk & Co. brand, as stated in Section 4.2.

Both group meetings were scheduled to last around 1 hour. As advised by McQuarrie (2016), a series of general topics for each discussion were developed, however the aim was to allow the participants the freedom to raise any issues important to them; hence the order of topics was not strictly controlled.

Each discussion involved a moderator and a note-taker. Additionally, audio recordings were made from both of them, to be transcribed afterwards.

Observations and hands-on sessions: In order to discover the needs involved in the installation process of the film, an aftermarket car body shop was visited. During the visit an observation was conducted of the film being applied by professionally trained applicators.

The observation did not follow a strict protocol, since the main goal of it was to explore the way in which currently the films are applied, and any latent needs, which may result from this process. Video material was produced from the observation, as well as notes were taken during it.

Another part of the visit involved the opportunity to learn the basics of film application process, in order to find any other aspects of the installation, which may not be visible to the observer not participating in this activity. This session was documented by video material and notes taken afterwards.

5.5 Identified needs

5.5.1 Method

Once all the discussions were carried out, all the audio files were transcribed in order to enable easy work with their content and compatibility with secondary data.

For all the transcribed material, notes and secondary analyses (PESTEL), a coding procedure was applied, as proposed by Creswell (2014), in order to define all relevant topics raised in the material. Codes are defined as general topics covered during the interaction, with associated specific interviewee statements or relevant pieces of text. The general division of codes was as follows:

- Added value proposals
- Attractive features of cars
- Design guidelines
- Local market characteristics
- Needs
- Production factors
- Problems
- Reference values
- Trade-offs
- Trends
- Other

The coding was carried out with a QDA software called NVivo 11 (QSR International, 2017). This allowed for all codes to be traced back to their references and easily ordered as needed. Full list of codes used for generation of need statements is shown in Appendix A.

The codes referring to the respective product expectations were then re-stated as need statements, to form a need list. It was attempted for the need statements to have a rather generic form, but also to reflect the language of the customers. This activity was followed by devising the K-J method, as proposed by Wallgren (2015), to group the stated needs into batches of statements concerning similar matters (Ulrich and Eppinger, 2011) in order to facilitate better organization of the list.

5.5.2 Results

Through the PESTEL analysis and the analysis of market trends, several high-level needs regarding the vehicle in general were found. These were translated to form the following high-level needs related to the films.

- The film shall contribute to high fuel efficiency of a vehicle.
- The film shall contribute to low environmental footprint of the vehicle.
- The film shall require minimum maintenance from users.

Majority of customers' and other stakeholders' needs were collected through direct interaction with them. These involve both stated needs, which were mentioned by the interviewees, as well as latent needs which had to be deduced from their other statements, as well as through observations and domain knowledge. Based on this data, a total of 60 need statements were generated, which were groups under 10 general categories, gathering needs affecting specific areas of product performance or value. Almost all the needs found in the secondary data research were also mentioned during the interactions with the stakeholders, thus confirming the validity of those needs.; the only exception being the recyclability of films, which was not explicitly

mentioned by any interviewee; however as defined as a latent need. The following categories of needs were found for the films:

- Manufacturability
- Maintainability
- Interaction with paints
- Surface quality
- Mechanical Properties
- Adaptability
- Durability
- Safety to humans and environment
- Fuel efficiency
- Value-adding features

Apart from the above, other kinds of needs and issues were discovered, which cannot be classified as product needs, but are still related to the product in more indirect ways. These groups will be discussed in Chapter 6. The full list of needs is presented in Table 5.2. The table also contains information regarding the type of films which the need refers to, and number by which they are to be identified in the specification table (Table 5.3). As apparent in Table 5.2, some need statements are marked with a letter (U). Such needs are deemed unfeasible in today's market. However since the patent analysis has shown that the technologies for satisfying such needs exist, they are kept in the list to indicate factors which may be of higher importance in future films. Needs with the (U) mark are mainly grouped under the *Value-adding features* category. Similarly, requirements relating solely to these need statements will also be marked in the same way in the specification table. Such requirements should not be treated with high priority at the moment.

Table 5.2: Complete list of needs. Statements market with (U) are assumed to be unfeasible.

Category	Need ID	Need statement	Film type	Kano class
Manufacturing	1.1	The film shall potentially be applied in an automated manner	All	E
	1.2	The film shall be possible to be applied in an ergonomically correct manner	All	M
	1.3	The film shall facilitate quick application	All	1D
	1.4	The application of the film shall be possibly cheap	All	1D
	1.5	The film shall be cheap to purchase	All	1D
Maintainability	2.1	The film shall facilitate stain-free washing at high external temperatures (U)	All	E
	2.2	The film shall contribute to easy cleaning	All	1D
	2.3	The film shall facilitate removal without any marks or damages to base surface	All	M
	2.4	The film shall facilitate easy repairs or self-healing of small damage	All	1D
	2.5	The film shall require minimal maintenance from the user	All	1D

	2.6	The film shall not allow any dirt to reside around its edges	All	M
	2.7	The film shall have hydrophobic and dirt-repellent properties	All	E
	2.8	The film shall not allow insects to stick to it	All	E
Paint interaction	3.1	The wrapping film shall be fully opaque unless otherwise required	Decorative	M
	3.2	The film colour shall match the standard colour requirements	Decorative	M
	3.3	The film shall have a seamless transition between its edge and painted surface	All	M
	3.4	The film should form a single surface and look like an integral part of a vehicle	All	M
	3.5	The film shall look similar to existing paints as much as possible	Decorative	M
	3.6	The paint-protection film shall be invisible for the user	Protective	M
Surface quality	4.1	No bubbles or wrinkles shall be present on the film after its application	All	M
	4.2	The film shall represent the same surface quality on both plastic and metal materials	All	M
	4.3	The film shall not have the "orange peel" look	All	M
	4.4	The film shall enable the droplets of water to form on its surface	All	E
	4.5	The protective film shall not alter the tactile feel of the surface	Protective	1D
	4.6	The film shall resemble the look of a metallic surface	Decorative	E
	4.7	The film shall not look like plastic or add-on sticker	Decorative	M
Mechanical performance	5.1	The film shall be resistant to scratching, abrasion and friction wear	All	1D
	5.2	The film shall be resistant to regular usage of car washes	All	1D
	5.3	The film shall be capable of stretching to assist heat expansion of base surface	All	M
	5.4	The film shall be resistant to stone chipping	All	1D
	5.5	If damaged, the film shall not dislodge from the surface	All	M
	5.6	The film shall be resistant to use of pressure washer	All	M
	5.7	The film shall have high adhesion to the base surface of different materials and paints	All	M
Adaptability	6.1	The film shall facilitate use of all desired graphic effects for vehicle customization (design flexibility)	Decorative	M
	6.2	The film shall facilitate quick change of its type used in production environment	All	1D
	6.3	The film shall be capable of rapidly changing appearance when required by the user (U)	Decorative	E
	6.4	The film shall be offered with custom thickness	All	E

	6.5	The film shall be available with desired gloss properties	Decorative	1D
	6.6	The film shall be highly reflexive to give the "deep" look of the surface	Decorative	E
	6.7	The film shall offer versions with different tactile feel	Decorative	E
Durability	7.1	The film shall be resistant to high temperatures of the environment, as well as from the vehicle itself	All	M
	7.2	The film shall resist high humidity conditions	All	M
	7.3	The film shall be resistant to sunlight, especially UV rays	All	1D
	7.4	The film shall be capable of fulfilling the criteria of Florida test (subtropical environment)	All	M
	7.5	The film itself shall be resistant to corrosion	All	M
	7.6	The film shall protect the covered component from corrosion	Decorative	M
	7.7	The film shall be resistant to contact with moisture	All	M
	7.8	The appearance shall not be affected by contact with chemicals	All	M
	7.9	The film shall not shrink over extended period of time	All	M
	7.10	The colour applied to the film shall not fade over extended period of time	Decorative	M
	7.11	If transparent, the film shall not become yellow over extended period of time	Decorative	M
Safety	8.1	The film shall not be toxic to humans or the environment	All	M
	8.2	The film shall be non-flammable	All	M
	8.3	The film shall be recyclable	All	E
	8.4	The film shall be safe when in contact with chemicals	All	M
Fuel efficiency	9.1	The film surface shall have good aerodynamic properties	All	1D
	9.2	The film shall be of low mass	All	1D
Additional features	10.1	The film shall control the amount of heat it absorbs (U)	All	E
	10.2	The film shall be able to behave like a solar panel (U)	All	E
	10.3	The film shall be capable of quick application and removal by the user for temporary use (U)	All	E

The needs were further assigned several attributes to enable their traceability, as well as to make navigation between different categories easier. The main attributes include:

- Reference code - name by which the need was coded. Following the code name, all associated stakeholders' statements can be found. All the codes with references can be found in Appendix A

- Source (which stakeholder/source mentioned this need)
- Importance rating - aiming to eliminate irrelevant needs and to indicate which of them bring the most value to the customer (shown in Appendix C).
- Main topic - this is aimed to support translating the need into its specific value drivers.
- Film type - shown in the table; indicates if the need relates to a specific type of film
- Kano class - further described below.

Each of the needs was also assigned a type according to a Kano model (Coleman, 2015). The main goal of the Kano classification was to indicate the character of needs and thus their priority in being satisfied. Three Kano types were used:

- **Must-haves (M)**: describing the most important needs which are non-negotiable for the functioning of product. However exceeding the performance of target value may not bring extra value to the product. (Hull et al., 2011)
- **One-dimensional needs (1D)** - needs which have a minimum value to be achieved, where an increase of performance in a given aspect is likely to increase the value of a product
- **Exciters (E)**: Needs which are fairly poorly satisfied by the solutions today and thus satisfying them is not necessary, but good implementation would bring a significant increase of product value (Coleman, 2015).

The Kano classes were assigned based on the results of need ratings obtained by surveys from users and internal stakeholders (details of the surveys can be found in Section 7.1, as well as based on domain knowledge and existing documentation regarding vehicle coating requirements.

5.6 Specification

Basing on the need list presented in Section 5.5 the full requirement specification was developed. In order to ensure that the process of translating needs into requirements is reliable and important aspects are not missed, the elements of so called Value Creation Strategy were employed (Isaksson et al., 2013). For each of the need statements, first a general topic of the need was determined, and then a set of value drivers was found. A value driver is a technical feature of a product, which affects the value perceived by the customer with regards to a given need (Isaksson et al., 2013). In this specification, each value driver is one technical requirement. Each value driver was accompanied by exactly one metric by which it should be assessed, and associated unit (where possible to determine), in order to ensure that all the generated requirements are measurable (Hauser and Clausings, 1996). This process was supported by analysis of the existing specifications for other coating methods devised by the company, as well as on data sheets provided by the film suppliers - these documents basing on decades of industrial experience provided information on aspects which may not have been obvious to the performance of the films.

Further, the testing methods and acceptance levels were found for the requirements.

For most of them, three target values are defined: mandatory, desired and best value (Hull et al., 2011). For the *must-have* requirements all of these values are usually the same, since increased performance won't bring additional value to the film (unless decided otherwise). For some of the *exciter* requirements the mandatory value, and sometimes desired values are given as **N/A**, because they are not mandatory to fulfill in all cases. The data for this activity was also sought for in existing specifications, however, because polymer films have not been widely devised by the company, major part of the testing methods was found in external technical standards, mainly issued by organizations such as ASTM or ISO. For determining the target values, data sheets of existing automotive films were also used. The differentiation of levels was based on industry practice as well - the requirement levels refer to the surface finish classes on vehicle exterior where applicable.

Several of the requirements also contain additional comments which explain the rationale behind a given requirement if it is non-obvious, or provide additional information. In particular, the comment section is used when the specific test method does not exist, or only an approximate or proposed one is stated, as well as when the target values are only proposed basing on existing products. The specification including test methods and comments is shown in Appendix B. Exact target values are not revealed due to sensitive character of this data.

Table 5.3: List of value drivers with their corresponding units.

Need	Value Driver	Metrics	Unit	Req.
1.1	Possibility of Automation	Possibility of Automation	Yes or No	1
1.2	Curling	Curling	As per test standard	2
	Elasticity	Young's modulus	Pa	3
	Adhesion after detachment	Peel-off adhesion	N/m	4
	Adhesive side recognizability	Presence of characteristic feature	Yes or No	5
1.3	Substrate preparation time	Substrate preparation time	min/m^2	6
	Steps involved	Number of steps for application	#	7
	Application time	time of application	min/m^2	8
	Time for preparation of film	Time for preparation of film	min/m^2	9
1.4	Equipment cost	Equipment cost	SEK	10
	Cost of consumables	consumables cost per hour	SEK/h	11
	Application time	time of application	min/m^2	8
1.5	Material cost	Material cost per area	SEK/m^2	12
2.1	Soap-Stain resistance	Wetting	As per test standard	13
	Heat absorption	Heat Absorption (U)	$W/(m^2 \cdot K)$	14
2.2	Stain resistance	Stain resistance	As per test standard	15
	Surface Roughness	Surface texture	As per test standard	16
	Glue residue left after removal	Area of residue left	mm^2 $/m^2$	17

2.3	Glue residue left after removal from heat-affected areas	Area of residue left	mm^2 $/m^2$	72
2.4	Self-healing properties	Self-healing properties	Yes or No	18
	Ability of repair with DIY paint repair kits	Ability of repair with DIY paint repair kits	Yes or No	19
	Polishing Quality	Polishing quality	As per test standard	20
2.5	Stain resistance	Stain resistance	As per test standard	15
	Scratch resistance	Scratch resistance	As per test standard	21
	Hydrophobic properties	Wetting	As per test standard	13
	Self-healing properties	Self-healing properties	Yes or No	18
2.6	Edge roughness	Edge Roughness	μm	22
	Adhesives around the edges	Presence of adhesive	Yes or No	23
2.7	Surface tension	Wetting	As per test standard	13
2.8	Adhesion of top surface	Cling adhesion	As per test standard	24
	Stain resistance	Stain resistance	As per standard	15
3.1	Opacity	Opacity	%	25
3.2	Colour deviation	Colour deviation	Grade	26
3.3	Surface roughness along the edge	Edge Roughness	μm	22
	Film thickness	Thickness	μm	27
3.4	Surface roughness along the edge	Edge Roughness	μm	22
	Edge visibility	Edge visibility	Yes or No	28
3.5	Colour deviation	Colour deviation	Grade	26
	Texture	Surface texture	As per test standard	16
	Gloss	Gloss	Gloss Unit (GU)	29
3.6	Transparency	Transmittance	%	30
	Edge visibility	Edge visibility	Yes or No	28
4.1	Adhesion	Peel-off adhesion	N/m	71
	Presence of bubbles	Presence of bubbles	Yes or No	31
	Features supporting bubble-free application	Features supporting bubble-free application	Yes or No	32
4.2	Gloss	Gloss	Gloss Unit (GU)	29
	Surface Texture	Surface Texture	μm	16
4.3	Surface texture	Surface texture	μm	16
	Orange peel look	Orange peel look	Yes or No	33
4.4	Hydrophobicity	Wetting	As per test standard	13
4.5	Surface texture uniformity	Variation in surface roughness	μm/mm	34
4.6	Gloss	Gloss	Gloss units	29
	Film thickness	Film Thickness	mm	27
	Edge roughness	Edge roughness	μm	22

4.7				
	Surface texture	Surface texture	μm	16
5.1	Scratch Resistance	Scratch Resistance	As per test standard	21
	Wear resistance	Rubbing wear resistance	As per test standard	35
5.2	Chemical Resistance	Reactivity with chemical substances	As per test standard	36
	Abrasion Resistance	Abrasion Resistance	As per test standard	37
	Nano-scratch resistance	Nano-scratch resistance	As per test standard	38
5.3	Elongation	Elongation	%	39
	Color deviation upon stretching	Color deviation	As per test standard	26
5.4	Stone Chipping Resistance	Stone chipping resistance	As per test standard	40
	Impact toughness	Impact toughness	J	41
5.5	Shear adhesion	Shear adhesion	N/m	42
5.6	Adhesion along the edges	Edge adhesion	N/m	43
	Pressure adhesion	Pressure adhesion	N/m	44
5.7	Surface Energy	Surface Energy	mJ/m^2	45
	Adhesion along the edges	Edge adhesion	N/m	44
6.1	Possibility to apply custom colour	Possibility to apply custom colour	Yes or No	46
	Printability	Printability	Yes or No	47
6.2	Storage in production environment	Possible to store in production area	Yes or No	48
6.3	Colour changing properties	Colour changing properties (U)	TBD	49
6.4	Thickness	Thickness	μm	27
6.5	Gloss	Gloss	Gloss units	29
6.6	High gloss	Gloss levels	Gloss units	29
6.7	Surface texture range	Surface texture	As per test standard	16
	Thermal conductivity of surface	Thermal conductivity	W/(m.K)	50
	Tacky feel on surface	Cling adhesion	As per test standard	24
7.1	Adhesion in high temperatures	Peel-off adhesion at high temperature	N/m	71
	Thermal expansion	Thermal expansion coefficient	1/K	51
	Minimum operating temperature	Minimum operating temperature	degree Celcius	52
	Maximum operating temperature	Maximum operating temperature	degree Celcius	53
	Elongation at low temperature	Elongation	%	39
	Hardness in high temperature	Hardness	As per test standard	54

7.2	Adhesion in humid conditions	Peel-off adhesion	N/m	73
7.3	Colour deviation over time	Colour deviation	As per test standard	74
	Texture change in time	Roughness change in time	μm/year	55
	Change in gloss over time	Gloss loss over time	%	56
7.4	Combined heat and humidity adhesion	Peel-off adhesion	N/m	75
	Change in colour at prolonged light exposure	Colour deviation	As per test standard	76
7.5	Corrosion resistance	Corrosion resistance	As per test standard	57
7.6	Moisture penetrability	Water absorption	N/cm	58
	Air tightness	Air tightness	As per test standard	59
	UV penetrability	Opacity	%	25
7.7	Water absorption	Water absorption	As per test standard	58
	Solubility in water	Solubility in water	Yes or No	60
7.8	Reactivity with chemical substances	Reactivity with chemical substances	As per test standard	36
7.9	Shrinkage	Shrinkage	%	61
	Elasticity	Young's Modulus	Pa	3
7.10	Colour deviation per time	Colour deviation	As per test standard	26
7.11	Yellowing of the PPF	Yellowing	%	62
8.1	Presence of toxic substances	Presence of toxic substances	Yes or No	63
	Toxicity after disposal	Toxicity after disposal		64
8.2	Flammability	Flammability	As per standards	65
8.3	Presence of Recyclable materials	Percentage content of recyclable materials	%	66
8.4	Reactivity with chemical substances	Reactivity with chemical substances	As per standards	36
	Toxicity of reaction products	Presence of standard Toxic substances	Yes or No	67
9.1	Friction drag	Friction drag coefficient	N/A	68
9.2	Mass per area	Mass per area	kg / m^2	69
10.1	Heat absorption	Heat absorption (U)	W/(m^2. K)	14
	Thermal Conductivity	Thermal Conductivity	W/(m. K)	50
10.2	Separate specification required			
10.3	Peel adhesion	Peel Adhesion	N / mm	4
	Application to stained surface	Adhesion to stained surface	N / mm	77
	Application with no specific tools	Usage of special or specific tools (U)	Yes or No	70

The full list of requirements is presented in Table 5.3 (value drivers and units) as well as in Table B.1 in Appendix B (test methods, target values and comments). In the requirement list, the test methods and target values are in major part proposals only, and setup of the final ones will require further testing. Also, as mentioned in Section 5.5, requirements which may not be feasible to products today are marked with **(U)**. The requirements are listed according to their corresponding need numbers, also apparent in Table 5.2. Therefore several requirements are repeated. For this reason the requirements are numbered independently and appear as duplicates in a table only to provide transparency regarding all the value drivers for needs. If a requirement is used more than once, its number is duplicated as well. A full list of requirements with no repetitions is presented in Appendix B. This measure was introduced to ensure their uniqueness, i.e.that one parameter is not tested multiple times for different acceptance levels (Hull et al., 2011).

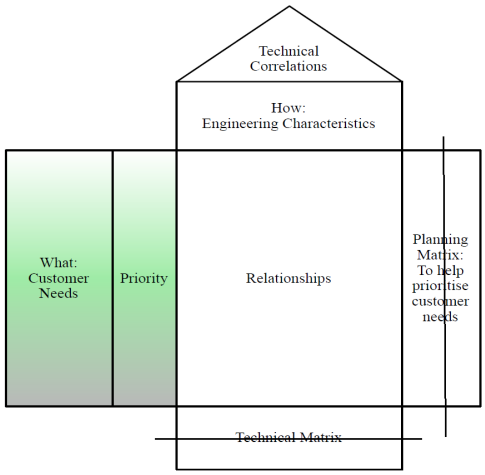


Figure 5.1: Schematic view of House of Quality. The unused parts are crossed out. Adapted from: Zhang (2012).

5.7 Customization of specification

The specification described in Section 5.6 is a general one - it contains factors applicable to both protective and decorative films which may be used in different areas of a vehicle. However, the need may arise to install the film only to a certain component of the vehicle, and hence, certain characteristics of a film may have higher priority than the others. In such cases, it is an industrial practice that while the film (or any given coating) has to fulfill all the specified requirements, only a handful of them will be specified for the component, and thus will need additional testing on the component level.

The simplest way to adjust the specification to specific cases is to use a number of attributes by which the whole specification can be filtered (Hull et al., 2011). It was decided, that in order to completely match the specification to a certain application, the following questions need to be answered:

- What kind of film should the specification consider? (protective/decorative/both)
- Which component will it be applied to? (doors, hood, roof etc.)
- How visible is the covered surface? (referring to internal surface class description)
- Which market segment is it prepared for (cost-oriented / performance-oriented)?

Answering all the above questions should result in context description of a form:

{*The film type*} to be applied on {*surface class*} surface of {*component*}.

For instance this context description could have a form of such sentence: "*The decorative film, to be applied on class A surface of door panel.*"

Accordingly, sets of attributes have been assigned to the requirements in the specification spreadsheet to enable filtering it in search for the applicable elements. These attributes (shown in table 5.4 are the possible answers to the questions above. By selecting the desired options from this table and filtering the specification with them in sequence shown in figure 5.2, the shorter version of the specification should be obtained. This specification only includes aspects which need to be specifically considered for films in a given vehicle component.

Table 5.4: Requirement attributes

Attribute	Possible values
Film type	Protective; Decorative
Area of use	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim (more can be added)
Surface class	A/B; C
Target	Performance oriented (Desired and Best values); Cost oriented (mandatory and desired values)

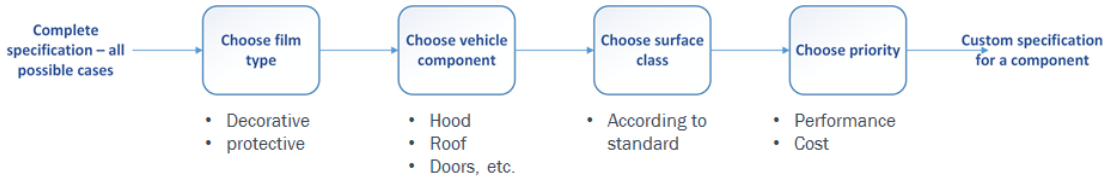


Figure 5.2: Sequence for customizing the specification table.

In case of attributes such as *area of use*, not all requirements are assigned a value. If this attribute is left blank for a requirement, it means that a given metric only needs to be tested when given film is introduced into company, and will not require separate testing after application to specific components. This particularly relates to requirements, for which testing may take an extended period of time, which could expand beyond the entire development cycle of a vehicle (long-term weathering). Also, some attributes (*surface class* and *target* are not present in the specification. However they are used to determine the correct set of target values for the associated requirements. Thus, the final choice of applicable target value should be as follows:

- Surface C; "cost" option - Mandatory Value
- Surface C; "performance" option - Desired Value
- Surface A/B; "cost" option - Desired Value
- Surface A/B; "performance" option - Best Value

In order to sort the duplicating requirements, as well as to identify potentially conflicting requirements, the House of Quality - a key part of Quality Function Deployment (QFD) methodology was employed, as outlined by Hauser and Clausings (1996). Since the use of the QFD is limited for this project, the process was simplified - only the first house described by Hauser & Clausing was devised, and only some parts of it were used - the main body and roof of the House of Quality (HoQ) (see Figure 5.1). In order to handle a large amount of data in an automated way, a template for the HoQ was used (QFD Online, 2007). In the composed matrix, the rows represent the need statements and the columns - associated metrics (needs from table 5.2 and metric from table 5.3. As part of the QFD it was also specified whether the given requirement calls for minimizing, maximizing or keeping a certain value of the technical parameter. This can be found in Table C.1 in Appendix C. Due to the size of a complete matrix (60x77) it could not be attached to this report in a readable version.

The performed QFD analysis also allowed to prioritize the requirements. Since this project does not concern the design of films, this feature can only serve as an indicator as to which parameters of sourced products should be of particular attention. The numerical value was assigned in the relationship matrix of the HoQ to indicate how much a given requirement affects certain needs. Basing on how strong the relationships are and how many needs the requirement affects, its relative weight was calculated. A complete list of requirements together with their weights is presented in Table C.1 in Appendix C. The ten most important requirements for customers' needs then turn out to be:

1. Surface texture - 6,65%
2. Colour deviation - 5.94%
3. Gloss - 4,35%
4. Peel-off adhesion - 3,72%
5. Reactivity with chemical substances - 3,07%
6. Edge roughness - 3,03%
7. Stain resistance - 2,67%
8. Scratch resistance - 2,66%
9. Thickness - 2,34%
10. Water absorption - 2,28%

Using the roof of the HoQ the interactions between the technical parameters were determined; it was found whether improving a given parameter can support or deteriorate any other features of the film. Table 5.5 shows a few of the most important positive and negative correlations between the technical requirements. Basing on this data, it is possible to prioritize the features of the film to handle the trade-offs, as well as to deduce the strong points of the offered films basing on incomplete data sheets which are often provided by the suppliers.

Table 5.5: Major interactions between technical requirement in the specification.

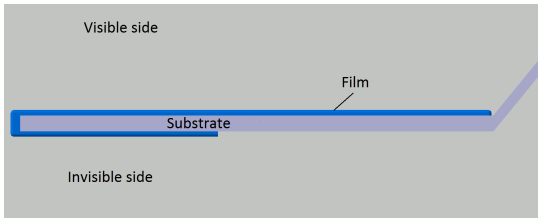
Strongest positive interactions	Strongest negative interactions (trade-offs)
Impact toughness & Scratch resistance	Transparency & Presence of recognizable feature on adhesive side
Thickness & Mass	Young's Modulus vs. Cost of Material per unit area
Thickness & Opacity	Scratch resistance & Mass per area
Peel-off adhesion & Shear adhesion	Peel-off adhesion vs. Curling
Stain Resistance & Corrosion Resistance	Self-healing vs. hardness
Thickness & Scratch Resistance	Thickness vs. Edge Roughness
Hardness & Stone Chipping resistance	Polishing quality vs. Gloss

The trade-offs shown in Table 5.5 can best be solved by referring to the weight rating of requirements shown in Appendix C, since it relates the requirements to how many needs and how strongly they affect - the requirement with higher rating should have a priority in fulfillment.

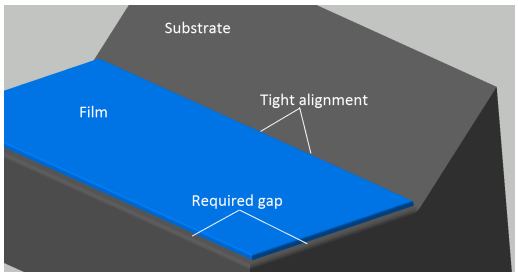
6

Recommendations

This chapter contains the results of the interactions with various stakeholders, and analysis thereof, which do not contain direct needs relating to the films, but provide interesting information in the context.



(a) Section view of film wrapped around the edge of substrate surface



(b) View of film aligned to surface corner and edge

Figure 6.1: Representation of design guidelines: 4 (a) and 6 (b)

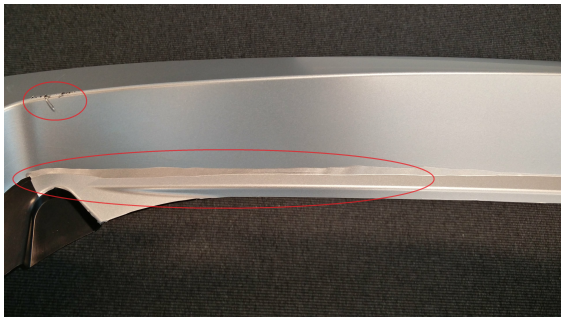
6.1 Design guidelines

The films are typically applied on top of the existing surfaces of the exterior components, wherever needed. This might result in a situation where the need for application of the films could have an impact on the design or the functionality of their respective substrate components. This was also expressed as a concern by several of the stakeholders during the interviews. Hence their suggestions and advice should be considered to develop the following set of generic design guidelines. The exact references to statements forming the baseline of these guidelines can be found in Appendix A.

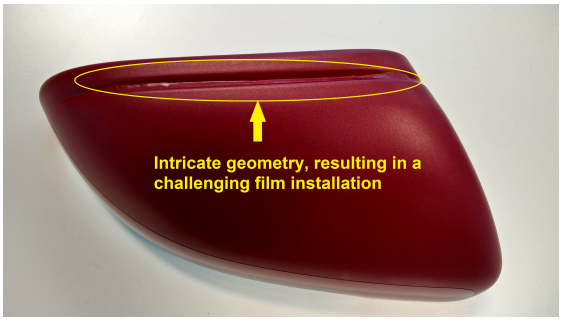
1. While designing intricate surfaces for the parts such as bumper fascia, it is recommended not to have a tight radius. Highly curved surfaces might cause extensive stretching of the film which in turn would affect the adhesion of the films to the substrate. Usage of complex curvature also significantly extends the time taken for film application as it requires special application techniques. This results in three major guidelines:
    - If the surfaces for film application are curved, the curvature shall be minimum 50 mm in radius (basing on observations of application) (see

Figure 6.2(a).

- Components with curvature only in two dimensions are more suitable for film application.
- If complex geometry cannot be avoided, alternative film application forms may be considered, such as hydrographic printing. This method however requires additional clear-coating.



(a) Adhesion problem on non-filleted corner.



(b) Fitting problems into a narrow slot.

Figure 6.2: Examples of problems caused by component geometry.

2. The gap and flush sizes between adjacent components need certain dose of attention. Most of the dedicated automotive films are considerably thicker than the layer of paint and coating. Hence, the dimensions and tolerances need to be adjusted to this size. Special attention is needed for components designed for two-tone colouring, when a film is applied onto a layer of paint, thus increasing thickness even further.
3. The strength of adhesion is governed by the surface energy of the substrate material. Thus it is vital to ensure that the surface energy is high and as a result there is a maximum attraction on a molecular level. To achieve this, certain surface preparation techniques might be required[1]. Particularly for plastic materials, it is essential to establish (basing on tests) which materials and with which treatment are suitable for film application.
4. In order to maintain high levels of perceived quality, it is essential that only one piece of film per component is used, so that the surface looks coherent. To achieve this, the following measures must be taken:
   - Avoid complex curvature as mentioned in point 1.
   - Avoid forcing film application to small surfaces, such as front grilles. In such cases (for plastic parts) film application through co-extrusion or hot stamping should be considered.
   - Avoid film application to components containing small slots or gaps (see Figure 6.2(b).
   - If the film is applied on a highly visible surface, it should be wrapped

[1] Anders Nyberg, CEVT AB; personal communication on 2017-03-31.

around the surface edge to hide the film edge (see Figure 6.1(a))

5. Fulfilling the above point may require changes to manufacturing or assembly procedures for some components. In order to ensure the quality of wrapping of the film around the substrate edges, the person installing the film must have easy access to both portions of the highly visible surfaces, until they are covered (see Figure 6.1(a)). In addition to this, any surrounding parts that are to be assembled onto these wrapped surfaces shall be mounted/assembled only after the film installation process is complete.
6. The user should not feel that a film is something which can be peeled off (see Section 2.4). Therefore, if a film is to be applied to the surface (especially if there is no possibility of wrapping it around the edge of thick components), attempts should be made to make the film edge as invisible as possible. This can be achieved through:
    - Aligning film edge to a corner between two adjacent surfaces (see Figure 6.1(b)).
    - Planning the film edge very close to the surface edge. Note: film edge cannot be exactly aligned with surface edge as this can impair the adhesion. A minimum of 1 mm has to be left between the edge of film and substrate surface[2] (see Figure 6.1(b)).

Figure 6.3: View of more than one piece of film on a surface.

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[2]Claes Larson; Ackert Reklam AB. Personal communication on 16th March 2017.

6.2 Supply needs

Some of the needs which were voiced by the stakeholders regard the qualities of the supplying company rather than the product itself. The needs which are presented below cannot be translated into measurable technical requirements, but should be taken into consideration in establishing relationships with potential suppliers of films.

- Need for customized colours - The LYNK & CO cars have a predefined set of color options for the upcoming model years. If the paint is to be replaced with a wrapping film, it is important to ensure that the colors of the paint and the film match perfectly. Film suppliers must be able to develop and deliver a film with custom colour matching the OEM requirements. This also applies to gloss options and other graphical effects such as patterns, prints or tinted coatings.
- Need for assistance in process and tooling development - Film installation on the OEM level requires a high level of precision and repeatability of the entire manufacturing process. Therefore the supplier with its knowledge of the offered products should be able to assist CEVT in developing the film application procedures. This also applies to all fixtures and tools, which may be specific to a given kind of film as well as a given component of a vehicle.
- Need for initial training - The process of film application demands the presence of skilled labour. Hence the company should account for the necessary training programs. Since the film suppliers have a pool of their certified dealers who are also well trained in the film installation techniques, it is highly recommended to collaborate with the film suppliers for well planned training programs for the internal labourers.
- Need for global capabilities - At the moment, manufacturing of the LYNK & CO cars are planned to happen only in China. However, production may be expanded in the future, to other countries as well, for increased capabilities. Thus, the supplier must be able to provide the films of consistent quality to the desired assembly points on a regular basis.
- Need for assistance with testing - It would be very expensive for the OEMs to have extensive test rigs for the validation of all the specifications intended for the film, since it is manufactured externally. Hence it is suggested that the supplier may support the OEM with verification and validation of critical technical requirements of the films, particularly for parameters which may differ between supplied batches.

6.3 Current Challenges

During the interaction with the internal stakeholders, a certain dose of reluctance to use the films was noted in some cases. Basing on their statements, main obstacles have been identified, which make the use of films risky on an industrial scale. Some of

these problems arise from the films themselves, while others are related to company capabilities and other factors.

Certain valid concerns with respect to the films itself were conveyed during the discussions. They are listed below as follows.

- Mass - polymer films are perceived as heavier than traditional paints and coats. While this notion needs to be verified as it is dependent on several other factors as well, it is a fact that films are significantly thicker, and that this thickness can vary greatly depending on the chosen film colour, which may to an extent affect the film mass.
- Geometry-dependence - it is known that films are not very well suited for complex geometries. However the exact definition of problematic geometries is not very well explored. Therefore the hesitation from using films may arise, partly based on experience, and partly on preventing the potential risk of unknown problems.
- The long-term durability of films is questioned in the industry. It is feared that over time the film may lose its properties, especially in terms of perceived quality (the 'plastic look' having been mentioned as a key factor). Adhesion under high temperature and humidity conditions is also of significant concern.
- Manual application - most types of films used for vehicle exterior are applied manually. Such application method raises concerns about the cost and time of application, but also about variation in results - the quality of finish may change from one shift to another and with the applicator's tiredness.
- User perception - some users claimed that they would be suspicious knowing that their car is covered with a plastic film - mainly due to quality concerns or assumptions that film was used to cover exterior defects.

The main production issues are:

- Limited space - introduction of films would mean the need to devote certain space both to film storage and installation. With current facilities providing limited possibilities in generating additional space, this may be seen as a problem. A factor further complicating this aspect is that film installation requires a relatively clean environment, which further increases the cost of establishing the installation zone.
- Limited testing capabilities - At the moment there is no indigenous test facility for Geely/CEVT in Gothenburg. As a result, several tests need to be carried out either in China or at external test labs. Thus, in addition to the costs accrued, dependency on external facilities are likely to cause significant delay in the development time for new technologies, including films.
- Initial costs and changes - The existing assembly layout is customized and optimized for the existing activities, over a significant period of time. If the new activity is to be incorporated, that would require significant changes to be made to the present layout. Additional tooling/fixtures development, training and resources needed to adapt the product and process generate significant initial costs for the company.

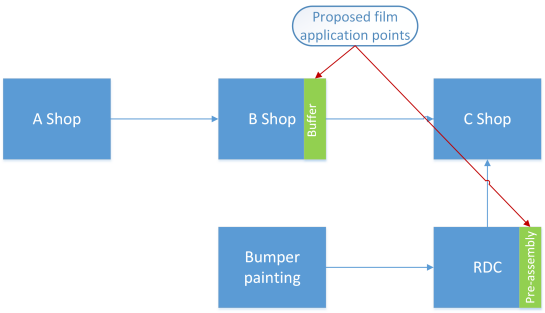

Figure 6.4: Diagram showing the proposed location of film application in assembly.

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Currently, it is not certain where the film application can take place. It was suggested that the stage of final vehicle assembly (C shop) should not be considered because of the short time that the car spends there[3]. Hence two solutions were proposed. One, concerning most of body-colour components, proposed the film application to take place in one of the buffer zones after the B shop (see Figure 6.4). Another, especially for bumpers which arrive to the C shop in a bit different way, is to locate film application in the pre-assembly area of the RDC shop[4]

6.4 Value-added proposals

In order to mitigate some product-related issues, especially those regarding trust towards the films as a reliable way of vehicle coating, some of the interviewed users have proposed means which would add value to the product itself. These proposals are listed below:

- Clear communication - the users would like to see the benefits of using films so that they do not perceive the use of foils as a cheaper, worse alternative.
- Added services - especially for long-term leases, part of the agreement can involve the offer to cheaply change the vehicle colour by applying a new wrap after some time of use. Alternatively, a part of the warranty could ensure replacement of film after scratching within a certain period.
- Insurance discount - especially when using the protection films, the body remains less prone to damage, hence enabling lowering the insurance slightly.

Due to changing distribution patterns and trends towards more direct contact between the OEMs and customers, CEVT is likely to have more freedom in the future to offer the services such as those proposed above. The business model of the LYNK & CO brand also enables easier implementation of them.

6.5 SWOT Analysis

A SWOT analysis was performed in order to synthesize the main factors which could affect the decision on whether or not to introduce the polymer films on body exterior. The data for this synthesis has come from various sources including interviews with stakeholders, as well as from information included earlier in this report. The top

[3]Håkan Thorsson, CEVT AB. Personal communication on 26th April 2017
[4]Bo Stahre, CEVT AB. Personal communication on 1st June 2017

half of the analysis in Table 6.1 is composed of internal factors - properties of films and internal capabilities of the company. The bottom half contains the external factors, mainly coming from the market trends shown in Chapter 4.

Table 6.1: SWOT Analysis

STRENGTHS	WEAKNESSES
• Low cost of material (Grefenstein and Kaymak, 2003) • Ease of producing visual effects (tint effects, pattern application etc.) • Superior impact/scratch properties at relatively low cost • Reduction in use of materials such as chromium • No emission of VOCs in application (Baitz et al., 2004)	• Labour-intensive application process (for metal substrate components) • Application sensitive to component geometry • Good surface quality required • Initial investment and training will be required • Relatively more sensitive to temperature changes • Some colours and graphic effects require development • Higher mass than that of paints
OPPORTUNITIES	**THREATS**
• Drive towards increased customization may favour quick change of appearance • Increased focus on environmental footprint of manufacturing process • More direct contact between the OEM and customer enables added services • Polymer film technologies evolving rapidly in the past decade.	• Uncertain reception of the use of films from the customers (perceived quality may be impaired) • Limited number of suppliers for certain films – potentially can affect price of films • Developments in paint technology may render the investment in films redundant

7

Validation and discussion

7.1 Validation

The stakeholder needs were validated in order to ascertain that the elicitation process obtained relevant results and that the generated need statements reflect real market expectations. This validation was performed in several ways described below.

A total of 2 surveys were prepared, one for all the internal stakeholders and the other for all the users. Both the surveys were of the same format, asking the participants to rate the needs in terms of their importance on a scale of 1 to 5. One survey contained only the customer needs and was shared with the users. The other survey consisted of the internal needs and was sent to the stakeholders within CEVT. The objective in splitting the needs between two surveys was in encouraging more participants to complete the surveys by making them shorter. It was assumed that the need would be deemed irrelevant if its average rating falls below 2,0. The results indicated a few needs with ratings between 2,5 to 3, however none of them was below 2. The complete list of need ratings can be found in Table C.2 in Appendix C.

Further validation was performed by the use of QFD method, as described in Section 5.6. Basing on the data obtained through the technical correlation matrix House of Quality, it was determined whether any requirements are conflicting, and if so, whether they should be addressed in a specific way or treated as trade-offs. Based on the relationship matrix of the HoQ it was also determined that a few of the requirements may be close to redundancy - they only affected single need and the relation was fairly weak. However, because of uncertainties inherent in the use of this method (described in Section 7.2.3), these requirements were not removed from the specification, only listed below to raise a critical attention. The potentially redundant metrics are:

- Curling
- Presence of adhesive on the edge
- Printability
- Number of steps to change film

As apparent, most of these requirements relate to the installation process. This may indicate either that this process will require further exploration to identify more relevant requirements, or that manufacturing issues were underestimated in the need elicitation process.

Finally, the requirements in the specification were validated for defects using a checklist proposed by Wiegers and Beatty (2013). Since the checklist considers mainly requirements for software development, it was abridged to only include the points relevant to all kinds of specifications. The list considers main factors for the quality of requirements specifications such as: completeness, correctness, quality attributes, organization and other issues (Wiegers and Beatty, 2013). Review of the developed specification against this list has shown that it has passed most off the criteria. It also confirmed that further work on the specification is needed by failing on the criteria that require all testing methods and target values to be present. The full checklist with results and relevant comments can be found in Appendix D

Concluding, Zhang (2012) states several criteria verifying the requirements quality, following the EIA 632 standard. These criteria are presented below and accompanied with a comment on how a given quality was ensured in the project:

- **Singularity** - ensured by numbering and elimination of duplicate requirements
- **Feasibility** - target values based on existing products and specifications. Subject to further verification.
- **Non-ambiguity** - continuous text limited in the specification; all data tabulated.
- **Completeness** - most of the requirements contain all essential attributes. Subject to further revision.
- **Verifiability** - Test methods provided where existing. Subject to further revision.
- **Consistency** - Conflicts examined with HoQ. Trade-offs identified.
- **Traceability** - attributes assigned to allow tracing from requirements to needs, and filtering on different levels.

7.2 Discussion

There are numerous factors which could have affected this study in some way. There are also several moments where different decisions could have been made. These decisions are justified and discussed in the paragraphs below.

7.2.1 Research approach

It was decided that the project would follow so called *waterfall* approach to the structure of requirement generation. This is a fairly simple approach presented by Ulrich and Eppinger (2011) as well as others and assumes that all relevant requirements are gathered prior to any design or prototyping actions. Such approach is criticized by Alexander and Beus-Dukic (2009), who argues that following this way cannot result in complete list of requirements unless the process is iterated several times, or the system under development is well known from previous experiences.

However, it can be argued that in case of this study, the latter of the above conditions

is satisfied. The project does not consider the development of a new product, but the selection from existing, proven and tested products. Also, the films are to be applied to a car exterior which is a well explored system and a range of specifications for existing coating systems exist as a knowledge base. The task of this project was to bring together two well known areas so that an automotive OEM can gain knowledge in the field of polymer films. Therefore it can be assumed the generation of the initial product specification with little prior testing or prototyping is a valid step, which allows to perform the task more quickly and without major loss of focus. Hence the use of simple methodology allowed to save time and resources for the project.

Also, it is a significant fact that a majority of available literature in the field of requirements engineering come from the background of software development. This field allows for higher flexibility in adjusting the product development process (Alexander and Beus-Dukic, 2009). However these concepts when adapted to more tangible products have to be modified, and often simplified to allow for more difficult testing circumstances and dependency e.g. on equipment suppliers.

7.2.2 Data collection

The data collection from secondary sources formed a relatively small part of the project. Yet, there are some factors which may have affected the amount or quality of data.

Firstly, the data was mainly collected from widely available sources such as market reports, white papers and journal articles. The depth of information obtained from such sources is often inconsistent, since they are aimed at different audiences. It can be stated that this is enough to obtain a general overview of the market, which was the main objective with the analysis of these documents. However this cannot be considered as an in-depth market analysis, and this project does not aspire to such standards.

Another factor, specifically related to patent analysis is that patents may not present the up-to-date state of technology because of the period between patent filing and its publication, which usually is around 18 months. Therefore the latest valid patent information is dated as mid-2015. Moreover the selection of patents for analysis was performed manually, based on their titles and abstracts, which, with several hundreds of search results, can leave a possibility that some of relevant patents were discarded while some irrelevant were included in the analysis. This factor was partly mitigated by the fact that only a statistical analysis was performed and hence, assuming that most of the patents were relevant, the statistical trends should still be visible despite some anomalies caused by invalid search results.

The data collected using interviews and group discussions yield some more areas for improvement. Above all, not all interviews could be recorded (2 of them were not recorded), mainly due to technical circumstances. Therefore some data, which was not noted down, could have been lost, which could not be the case with recorded and transcribed files. Furthermore, it may be argued that contacting only one or few representatives of each stakeholder group may have not captured all the

important expectations. Finally, there is an inherent risk that some statements were left unnoticed. This is only partly mitigated by attaching the full list of codes and references to this report (see Appendix A).

However, in the process of data collection it was found that a majority of the captured needs were mentioned by more than one interviewee (more than one reference per code); this suggests that interviewing even more participants would have only resulted in the confirmation of the needs gathered till then rather than unveiling more expectations. Moreover, with 9 individual interviews and 2 focus groups and an observation session, it is statistically proven that most of the major needs are captured (Ulrich and Eppinger, 2011). Performing more interactions is still likely to improve the precision of the collected data (use cases, specific values for requirements etc.), but the accuracy would likely not change significantly. Hence, considering the time restrictions for the project, the amount of interactions is considered satisfactory for the results.

It also needs to be mentioned that the whole study i.e the elicitation of needs and validation of them were performed primarily based on group of users available locally. While this means a fairly wide ethnic diversity, the age and occupation of most participants were similar (predominantly students under 30 years of age). This age group however suits fairly well into the target market aimed by the LYNK & CO brand, which should be considered a positive coincidence.[1]

At the same time, it can be argued that the geographical bias is inclined slightly towards Europe. Since the considered product is to be launched globally, the ideal study should concern more diverse customer group. However, since this problem is not considered as urgent because of no geographical target market stated by the company.

7.2.3 Results

A total of 60 needs were captured. This lies within the range stated as a reasonable number of elicited needs according to the literature claiming a range for a product as 30-100 statements(Ulrich and Eppinger, 2011) (Hauser and Clausings, 1996). It is especially true considering the relative simplicity of the product under discussion and its structure.

The translation of needs into value drivers i.e. requirements was based on the domain knowledge of the films and automotive industry, as well as on the existing specifications for other coating methods. Creation of such specifications usually demands extensive experience in the given field, which induces a risk of some aspects being omitted or added redundantly. In order to mitigate this risk at least partly, this translation process was taken in smaller steps as proposed by Isaksson et al. (2013) by first defining the relevant field for the need and then finding a value driver and metric. As shown in the validation process, this may still leave single items being less relevant, which yields further refinement of the specification in the future. However the multi-step procedure is considered an effective and safe tool for this

[1] Andreas Kåreby, CEVT AB. Personal communication on 3rd April 2017.

task.

Further implementation of the Value Creation Strategy was attempted in order to provide the company with means to easily adapt the requirements to changing market needs. Such implementation would involve the 10 categories of needs, which could be used as value dimensions, which can be prioritized according to needs to develop different use contexts (Isaksson et al., 2013). However it was found that the translation from the rating of value dimensions to value drivers could create some unexpected effects resulting in highly arbitrary weights of the single requirements. Therefore in order to prioritize the requirements with this method, far deeper expertise in the automotive industry, and especially in the field of coatings is required.

The use of House of Quality has been recommended by numerous sources (Zhang, 2012)(Ulrich and Eppinger, 2011). However it largely relies on the judgment of its creators and assumes their high level of expertise. Since the expertise of the users of QFD in this case cannot be objectively measured, the results of its use need to treated with caution. A significant advantage of this tool was found to be the ability to perform several functions at once - both at a method for prioritizing and validating the requirements. Some problems were however faced in the visual representation of the complete matrix, which made the general overview of results difficult. use of existing templates, which change the visual structure of the HoQ enabled the analysis of results of this method.

Finally, it can be argued that the generated requirements, and in particular their acceptance levels (or target values) should be verified by laboratory testing or other testing methods in order to ensure that these values are feasible. This could not be performed for numerous reasons, including no access to testing facilities, time constraints and scope constraints - some of the required tests could last for up to several years. Additionally, since the polymer films are a fairly new product among automotive OEMs, the test methods for some of the generated requirements are not yet developed and standardized, and development of testing methods falls beyond the scope of this thesis. In order to mitigate these drawbacks and give a basis for further work on the specification, industrial standards which appear close to the desired scopes of tests were found and included in the specification, and acceptance levels which refer to such requirements were marked as proposed values only.

8

Conclusion

The major goal of this project was to explore the field of polymer films in the automotive industry and basing on that, develop the initial specification for the use of such films in a vehicle exterior. This specification was created, where most of relevant requirements are defined based on discovered customer and stakeholder needs. 58 out of 77 defined requirements are also assigned proposed test methods and target values. Customization of the specification to use on specific car components is enabled by the use of attributes assigned to the requirements. Validation of the results was performed on the level of needs, single requirements as well as the whole specification. It proved that needs are relevant, each of them is associated with at least one technical requirement and that the specification is formed correctly. The specification has however been shown to lack certain elements (mainly target values) which forms the main scope for future work.

Another result of this project comprises a set of recommendations to the company regarding both guidelines for component design to facilitate film installation, as well as other needs and challenges which will have to be considered when introducing films to mass production. Overall it is believed that all the outcomes of this project provides a solid basis for future developments in the field of exterior films.

8.1 Further work

This project resulted in developing only the initial version of the specification. A lot of fields were found to require further exploration, and experimenting, especially with respect to the technical properties of the films. The natural continuation of this project will involve activities such as the following.

- Several requirements were found, which are exclusive to the polymer films. Since this is a new domain for CEVT/Geely, the new specifications have to be completed through the identification, development and subsequent implementation of accurate test standards. Basing on these standards, sets of target values are to be developed to match the stakeholders' needs. The need list attributes and comments to requirements are to support this process.
- Extensive testing needs to be carried out in order to find whether the determined requirements have a significant impact on product value. The testing should also help refine the target values for the requirements. Attributes as-

signed to the requirements should also be reviewed following the tests - especially the *area of use* requires a revision by experts in each of the fields concerned.

- Additional requirements, especially concerning the manufacturing and assembly details shall also be added to the specification. The values for existing requirements can also be further split between high and low gloss options, following an expert revision.
- Some of the product characteristics may vary significantly between supplied batches, while others are likely to be less affected by manufacturing variation. Also, testing of some parameters is extremely time consuming and thus impossible to carry out for each batch of product. Therefore the scheme of testing needs to be developed, which will determine how often the supplied films need to be tested against given requirements.
- In order to ease the customization of the product specification, a simple database-run application can be created which would have the attributes as inputs and the processed specification as output.

There are also ways in which the results of this study can be developed to increase the scope of knowledge or provide more detailed data:

- The customer needs were elicited and validated basing on a limited group of car users (see Section 7.2.2). The scope of the study could be significantly increased by comparing and contrasting the elicited needs in other geographical areas. In particular, since an important market for CEVT lies in China, a separate need elicitation study could be performed for this market.
- Since the polymer films are to compete with traditional paints, this yields for a thorough comparative study, or a series of them, comparing the two processes.Currently the amount of available data doe not allow for a reliable comparison of costs or lead times of these two processes. Additionally, the studies could concern technological, environmental and manufacturing aspects, and would ideally give a perspective on the future solutions, because, as it was shown, the technology developments both for films and other coatings are continuously increasing (see Section 4.4).
- The focus of this project concerned mainly the types of films which are already in use in the automotive market. With sufficient growth in terms of knowledge as well as expertise in the field of polymers, this can be significantly extended. Polymer manufacturers provide a range of engineering films and it is possible that a film, which currently is intended for a different application, may be proved suitable for automotive industry as well.

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A

Appendix - List of codes and references

This appendix contains the gathered codes from interaction with stakeholders. Table A.1 shows which codes are related to which of identified needs. It is followed by all the codes with all referred transcript fragments.

Table A.1: List of codes supporting needs

ID	Code name
1.1	Need for automation in painting
1.2	Need - production ergonomics
1.3	Problem - slow application
1.4	Need - production dependent on Volvo
1.5	Need - production dependent on Volvo
2.1	Need - no stains when washing in sun
2.2	Need - ease of cleaning
2.3	Need - removal without marks
2.4	Need - easy fix
2.5	Need - ease and foolproofness
2.6	Need - no dirt around edges
2.7	Need - hydrophobic need, dirt-repellent
2.8	Need - bugs not sticking to surface
3.1	Need - opaque coat (For PRF)
3.2	Need - colour match
3.3	Need - smooth edge
3.4	Need - integrity
3.5	Need - same as paints
3.6	Need - PPF invisible
4.1	Need - no bubbles
4.2	Need - same surface quality on plastic and metal
4.3	Need - eliminate orange peel
4.4	N/A
4.5	N/A
4.6	Need - metallic feel
4.7	Need - no cheap, sticker feeling
5.1	Functions - scratch resistance
5.2	Need - car wash resistance
5.3	N/A
5.4	Need - stone chipping resistance
5.5	Need - film not coming off after damage
5.6	Ned - resist pressure washer
5.7	Need - adhesion to paint or other material
6.1	Need - something unique
6.2	Need - change colour quickly in production
6.3	Value added proposal
6.4	Need - controlled film thickness
6.5	Need - different gloss properties
6.6	Need - deep look of paint
6.7	Need - different tactile feel
7.1	Need - resist temperature
7.2	Need - resist humidity
7.3	Need - UV stability
7.4	Need - fulfill Florida test
7.5	Function - corrosion protection
7.6	Function - corrosion protection
7.7	Function - corrosion protection
7.8	Function - corrosion protection
7.9	Need - no shrinkage
7.10	Need - no fading colour
7.11	Need - control appearance change
8.1	Need - non-toxic films
8.2	Need - non-flammable
8.3	PESTEL
8.4	N/A
9.1	Need - Aerodynamic properties
9.2	Need - low weight
10.1	Value added proposal
10.2	Value added proposal
10.3	Value added proposal

Name: Far-fetched exciters
<Internals\\Focus Group 2> - § 3 references coded [1,83% Coverage]
Reference 1 - 0,83% Coverage
LM: I think it would be nice with a feature like if you are living in a warm country, that the film cools the car; and if it is here in Sweden, that it contains the heat or something. I don't know if it is possible.
Reference 2 - 0,71% Coverage
LM: Doesn't TESLA have this, like uh, the plate is solar panel, it's like only a film that's on the roof, like really thin. If you can cover your car with this film, that would be nice.
Reference 3 - 0,29% Coverage
RR: You polarize it.
VS: Yeah you can just polarize it and it should work.

Name: Function - corrosion protection
<Internals\\Focus Group Transcript> - § 1 reference coded [0,25% Coverage]
Reference 1 - 0,25% Coverage
And protection against...?
JT: Corrosion.

Name: Function - customization
<Internals\\Focus Group Transcript> - § 1 reference coded [0,38% Coverage]
Reference 1 - 0,38% Coverage
different people would like to have different colours on a car.

Name: Functions - scratch resistance
<Internals\\Focus Group 2> - § 1 reference coded [0,19% Coverage]
Reference 1 - 0,19% Coverage
You can see that it has been used, like scratches
<Internals\\Focus Group Transcript> - § 2 references coded [2,10% Coverage]
Reference 1 - 0,13% Coverage
and Car-wash resistant.
Reference 2 - 1,96% Coverage
JT: Of course, we need to fulfill requirements for humidity, sound, aging and things like that. That is a little risky. And we also talk about if it will be scratch resistant; if it will be glossy/ matte maybe, for example. Also appearance changing during the time, say. Also I think the application in our production. How do we apply it?
<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 1 reference coded [0,20% Coverage]
Reference 1 - 0,20% Coverage
Or maybe it could be better resistant to scratches
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,22% Coverage]
Reference 1 - 0,22% Coverage
Of course, appearance, but also, I think the major thing is scratch resistance,

Name: Need - resist pressure washer
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 2 references coded [1,44% Coverage]
Reference 1 - 0,89% Coverage
UV stability, changing the colour after 1 year, 2 years, and the other one is clearly the adhesion. You know, when there\s this high-pressure washer, the OEMs have these tests where there is a panel, there's actually a cross, and they put damage to it; it is extreme. And if you want you can test every system not right.
Reference 2 - 0,54% Coverage
Consider, if it's foil and you have it on the body and somebody is holding the high pressure washer right here [above and at the edge to the edge of foil], at this angle, what is going to happen.

Name: Need - same as paints
<Internals\\Focus Group 2> - § 2 references coded [0,98% Coverage]
Reference 1 - 0,34% Coverage
RR: Also I'll ask about the maintenance. Should I take it to a car wash? Can I polish it?
Reference 2 - 0,63% Coverag
VS: I think you can convert that to one thing. *Does it replace paint? Can I use the car exactly the same as if it were to be painted?* Then we would be okay with it.
<Internals\\Focus Group Transcript> - § 1 reference coded [0,65% Coverage]
Reference 1 - 0,65% Coverage
As long as it is not worse than paint; it should have similar specifications and abilities. It cannot be worse.
<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 2 references coded [0,75% Coverage]
Reference 1 - 0,44% Coverage
Having said that, we cannot have any bubbles or it should not look like a film - it should look like a paint
Reference 2 - 0,32% Coverage
how will you repair it? Do you need to remove all the film and apply a new one?

Name: Need - various colours
<Internals\\Focus Group 2> - § 1 reference coded [0,76% Coverage]
Reference 1 - 0,76% Coverage
LM: I think that you need to limit the customers. Because if you give them too much freedom, it would hurt the brand, because they can make it look ugly. So you need to limit their combinations.
<Internals\\Focus Group Transcript> - § 2 references coded [1,67% Coverage]

Reference 1 - 0,41% Coverage
Yeah, we really need a lot of colours, for we have different customers,
Reference 2 - 1,26% Coverage
So around 10 and 15 colours is the usual amount of different colours you need for a vehicle because we cannot just sell black cars or red cars. We need a lot of different colours. That is from the market pretty much.
<Internals\\Interview with 3M - product manager and key account manager> - § 1 reference coded [1,69% Coverage]
Reference 1 - 1,69% Coverage
the films should retain the paint colour and the glossy/matte effect

Name: Need - adjustproduction process
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,46% Coverage]
Reference 1 - 0,46% Coverage
Coming back to one of your questions between foil and paint, in foil, depending on where the foil has to go, you may need to take off/dismantle one of the components

Name: Need - aero properties
<Internals\\Focus Group 2> - § 1 reference coded [0,47% Coverage]
Reference 1 - 0,47% Coverage
VS: And also I want to know, being me, that would it have the same surface friction as if I were to go for a painted car?
Name: Need - avoid certain areas in production
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,30% Coverage]
Reference 1 - 0,30% Coverage
So that is something doing two-tone; need to make sure that the foil is not touching any of the strong areas.
Name: Need - bugs not sticking to surface
<Internals\\Focus Group 2> - § 1 reference coded [0,77% Coverage]
Reference 1 - 0,77% Coverage
AS: You know what it is: it's the bugs. And also when you take it on highways and stuff you usually have these insects, especially in the front and in the grille region, and that's something annoying.

Name: Need - car wash resistance
<Internals\\Focus Group 2> - § 1 reference coded [1,63% Coverage]
Reference 1 - 1,63% Coverage
VS: when you wash a car and when you use a slightly worn out cloth, you do the circular motion, you get those wrinkles on the car. And I, particularly on my dad's car, there were so many wrinkles after I washed it (I used the two-bucket system, I was really nerdy with all that stuff), but then I still used to get the wrinkles, ring-marks. So we had to go, get it polished to get it removed. Because it becomes so annoying.
<Internals\\Focus Group Transcript> - § 2 references coded [0,38% Coverage]
Reference 1 - 0,11% Coverage
Car-wash resistant.
Reference 2 - 0,27% Coverage
And make that *matteness (sic)* don't disappear
Name: Need - change colour quickly in production
<Internals\\Focus Group Transcript> - § 4 references coded [3,23% Coverage]
Reference 1 - 0,22% Coverage
Quick way of getting different (look).
Reference 2 - 1,19% Coverage
The application; because usually you have like a difference in cars to different customers. It should be very easy to change, in our process, in our plant, to produce variations or the variants very easily.
Reference 3 - 1,04% Coverage
Yeah exactly. If we are quick in making different appearances / different editions or like we talked about the collections such as the Spring collection, Autumn collection, etc.
Reference 4 - 0,78% Coverage
You could be happy about if it would be possible to exchange the colour from one day to the other and still keeping the same process.
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [1,55% Coverage]
Reference 1 - 1,55% Coverage
you know for a bumper, you paint 2-6 on one skin at the same time. So the output is a lot higher on the vehicle. The Output on bumpers, you are getting a lot more parts per hour. On a body, it is simply to the size. So the batch material for the batch on the body is probably going to see a colored change. For example, faster on a body, and then you will see on a bumper; because for the bumper, I have a batch that is going to last 4-6 weeks. During that time, I painted, say 5000 bumpers. I am not going to paint 5000 cars in that same color in 4 weeks.

Name: Need - clean production
<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 1 reference coded [0,33% Coverage]
Reference 1 - 0,33% Coverage
It should really be a clean room so that you don't have any dirt particles in it.
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 4 references coded [2,01% Coverage]
Reference 1 - 0,99% Coverage
if you have dirt particles on it and you're trying to be really really accurate, and any little imperfection, you'll see it. Of course it has to do with the colour combination also - white over black, black over white. You see it more than in black over dark-blue or something. So that comes in as well - what is the target, what is the colour combination.
Reference 2 - 0,40% Coverage
you need to put it on without any bubbles, imperfections, I mean anything with the foil will be visible. So [you need] the dust-free environment
Reference 3 - 0,53% Coverage

Everybody around working with it, it's not going to help if you have open containers since everything is clean and then the maintenance crew comes in, working on it, they don't have any clue.

Reference 4 - 0,08% Coverage

A big No-No is always Silicone

Name: Need - colour match

<Internals\\Focus Group Transcript> - § 1 reference coded [0,57% Coverage]

Reference 1 - 0,57% Coverage

if we mix the 3 mm paint, you can't really have a mismatch between them. That's obvious, at least.

<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 2 references coded [2,67% Coverage]

Reference 1 - 0,84% Coverage

we need to look at the colour matching because for example the door exterior, door handle can be painted by the supplier, and then that colour should match the colour of the sheet metal that we paint ourselves

Reference 2 - 1,83% Coverage

It is also a problem with color matching. We have a factory that is painting the body and the bumpers. And if you buy the door moldings, door handles, roof antenna and the spoilers, if they should be in the body color, you need to make sure that the supplier uses the exact same color and the process, so that the colors match among all the suppliers. For example, you can have a bluish white spoiler and the car is yellow white, it looks really bad.

Name: Need - controlled film thickness

<Internals\\Focus Group Transcript> - § 1 reference coded [0,57% Coverage]

Reference 1 - 0,57% Coverage

if we mix the 3 mm paint, you can't really have a mismatch between them. That's obvious, at least.

<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,21% Coverage]

Reference 1 - 0,21% Coverage

the thickness of the foil - you don't want to deal with something that's 3mm

Name: Need - cost of material

<Internals\\Focus Group Transcript> - § 1 reference coded [0,14% Coverage]

Reference 1 - 0,14% Coverage

The cost is one of them,

Name: Need - deep look of paint

<Internals\\Focus Group 2> - § 2 references coded [2,16% Coverage]

Reference 1 - 1,74% Coverage

. And also when I look at the paint, when I go closer and you can see that there's a car that's painted well and a car that is not painted well - you can see the shine of the car, if it is well polished, the finish of the car, like from far off you can see the light glare on it, if you see the gloss, if you see the quality of the paint as well, like you can see it's deep. To do a good paint you can't see the white. So like, final details as well.

Reference 2 - 0,42% Coverage

LM: I think that with white cars, they look less premium, because I think they look like flat in the colour.

Name: Need - different tactile feel

<Internals\\Focus Group Transcript> - § 2 references coded [3,34% Coverage]

Reference 1 - 0,34% Coverage

The feeling could be like metal cone or something, soft.

Reference 2 - 2,99% Coverage

AB: You mean if it should be soft/hard? You mentioned if it should be cool or warm feeling?

AR: Depending on where you touch it. If it is a lush and muscular shoulder, yeah and if you are gonna stroke with your hands, then it has to go over a curved surface, right? That is some characteristics you have to solve. If it is a smaller piece, maybe, it's the differences from paint to film and there's communication to your hand, maybe that's interesting. I mean it could be very different aspects there in my guess.

Name: Need - diffferent gloss properties

<Internals\\Focus Group Transcript> - § 1 reference coded [0,52% Coverage]

Reference 1 - 0,52% Coverage

One thing we have to look into very much is the combination of high-gloss and low-gloss.

<Internals\\Interview with Anders Bergstrom - senior designer> - § 1 reference coded [0,73% Coverage]

Reference 1 - 0,73% Coverage

- High Gloss vs. Low Gloss

Name: Need - ease and foolproofness

<Internals\\Interview with Marketing _ Branding> - § 1 reference coded [1,78% Coverage]

Reference 1 - 1,78% Coverage

And that doesn't necessarily mean that they don't want a car but that's what they say because they feel that it is a lot of hassle to own a car, to have a car, to buy a car; everything around a car is a lot of hassle. But this is important - they want mobility.

Name: Need - ease of cleaning

<Internals\\Focus Group 2> - § 3 references coded [3,86% Coverage]

Reference 1 - 0,78% Coverage

RR: I would say also if the gaps between the rear mirrors, if there is a gap and the water gets there, then when you are drying the car and there is always the stain of the drop. That really annoys me.

Reference 2 - 2,31% Coverage

What happens is: you're trying to get as much off [dirt] with the water as you can, but then there is a small residue remaining of either soap or dirt itself. And then it's really hard to get it off and you can feel that when you wipe the metal part and then you come towards the plastic part, the paint is actually not exactly as good as the other one, so you sort of, don't know if it is clean or it is just how it is. Especially on an older car which I have, and which is a bit sort of beaten with all the Indian road chips that sort of hit it, so it's a bit tough to clean know if it is clean.

Reference 3 - 0,77% Coverage

AS: You know what it is: it's the bugs. And also when you take it on highways and stuff you usually have these insects, especially in the front and in the grille region, and that's something annoying.

<Internals\\Focus Group Transcript> - § 1 reference coded [0,13% Coverage]

Reference 1 - 0,13% Coverage

and Car-wash resistant.

<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,08% Coverage]

Reference 1 - 0,08% Coverage

cleaning, when you wipe over

<Internals\\User Interviews - Tomasz Przybylek> - § 1 reference coded [1,30% Coverage]

Reference 1 - 1,30% Coverage

I can't expect to clean it by itself but maybe a car with such a film would be easier to clean. Or it would tay brand new for longer time.

Name: Need - easy fix

<Internals\\Focus Group 2> - § 1 reference coded [0,32% Coverage]

Reference 1 - 0,32% Coverage

LM: And if there's a scratch, do I need to change the whole film or can it be fixed?

Name: Need - eliminate orange peel

<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 1 reference coded [0,76% Coverage]

Reference 1 - 0,76% Coverage

So we look at the painting execution when it comes to orange peel, if you look at some cars they have this - looks like a surface of an orange fruit, and that's something we want to avoid.

<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,35% Coverage]

Reference 1 - 0,35% Coverage

Higher the paint, the more paint, becomes a limit for the adhesion and appearance. Orange Peel is something important on foils.

<Internals\\Marcus Schill - Bumpers and Claddings systm manager> - § 1 reference coded [0,56% Coverage]

Reference 1 - 0,56% Coverage

For painted parts the requirements are: smooth and without orange peel.

Name: Need - film not comming off after damage

<Internals\\User Interviews - Tomasz Przybylek> - § 1 reference coded [1,09% Coverage]

Reference 1 - 1,09% Coverage

It's also important that in case of a scratch or some impact, the film doesn't start coming off from the entire area.

Name: Need - hydrophobic need, dirt-repellent

<Internals\\Focus Group 2> - § 2 references coded [0,74% Coverage]

Reference 1 - 0,42% Coverage

TS: In rainy days, I don't know what the cause is, but you always have this muddy-ish [stuff]. It's terrible.

Reference 2 - 0,32% Coverage

VS: I would want it to shrug off the dirt, sort of, like a dog.

EJ: Yeah, exactly.

<Internals\\User Interviews - Tomasz Przybylek> - § 1 reference coded [0,39% Coverage]

Reference 1 - 0,39% Coverage

Is it possible to have a hydrophobic film?

Name: Need - integrity

<Internals\\Focus Group 2> - § 4 references coded [1,77% Coverage]

Reference 1 - 0,19% Coverage

So you feel the sync between the specific parts.

Reference 2 - 0,57% Coverage

there is a black strip running on the sides of the car, which is a part of the car. So it sort of adds character to it, maybe; so I would be okay.

Reference 3 - 0,61% Coverage

LM: Like if you have a surface and you put the film only here, you shouldn't see the line between like.. 'Oh I can rip off here!'. Shouldn't be like a sticker.

Reference 4 - 0,40% Coverage

But maybe not if it was for five years, then I would want it to be a part of the car and be able to show.

<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 3 references coded [1,92% Coverage]

Reference 1 - 0,76% Coverage

We want harmony in the vehicle and we don't want things to stick out and look like add-ons, so we want to have a… yeah, it should look robust basically, so that's what this area is about.

Reference 2 - 0,37% Coverage

they want something that looks clean and neat and they want to have one surface, basically.

Reference 3 - 0,79% Coverage

if you stand by the vehicle and look at it, I think the appearance is the main. I mean that it should like, the design should really be clear and you should not be having any disturbing elements.

<Internals\\Marcus Schill - Bumpers and Claddings systm manager> - § 1 reference coded [0,56% Coverage]

Reference 1 - 0,56% Coverage

For painted parts the requirements are: smooth and without orange peel.

Name: Need - last long

<Internals\\Focus Group 2> - § 1 reference coded [0,24% Coverage]

Reference 1 - 0,24% Coverage

RR: Yeah probably I will ask how long this wrapping would last

<Internals\\Focus Group Transcript> - § 2 references coded [4,62% Coverage]

Reference 1 - 1,96% Coverage

JT: Of course, we need to fulfill requirements for humidity, sound, aging and things like that. That is a little risky. And we also talk about if it will be scratch resistant; if it will be glossy/ matte maybe, for example. Also appearance changing during the time, say. Also I think the application in our production. How do we apply it?

Reference 2 - 2,65% Coverage

AN: Also regarding these transparent, protective films that they kind of change colour and become yellow-ish. It's supposed to be solved with newer films but I think there is still a big uncertainty regarding this, lack of testing knowledge. Development is happening very rapidly in the films but to many people in the automotive business it's well known that these transparent protective films won't stay transparent for very long, it will become yellow.

<Internals\\Interview with 3M - product manager and key account manager> - § 1 reference coded [1,69% Coverage]

Reference 1 - 1,69% Coverage

the films should retain the paint colour and the glossy/matte effect

<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 1 reference coded [0,31% Coverage]

Reference 1 - 0,31% Coverage

Because some of our requirements are that the car should last for ten years

<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 2 references coded [1,18% Coverage]

Reference 1 - 0,29% Coverage

especially in Europe, quality, to last for five or ten years because that's how long they own a vehicle

Reference 2 - 0,89% Coverage

UV stability, changing the colour after 1 year, 2 years, and the other one is clearly the adhesion. You know, when there\s this high-pressure washer, the OEMs have these tests where there is a panel, there's actually a cross, and they put damage to it; it is extreme. And if you want you can test every system not right.

<Internals\\User Interviews - Tomasz Przybylek> - § 1 reference coded [1,90% Coverage]

Reference 1 - 1,90% Coverage

You might have an expectation as to even after so many days/months/years, my car should look as if it was bought just yesterday. Do you have any such expectations from a car?

I think, up to Three years.

<Internals\\User Interviews- Ray Zhang> - § 1 reference coded [1,46% Coverage]

Reference 1 - 1,46% Coverage

And how long would you expect to own a car?

3 years. And in Sweden I'll probably buy a V40

Name: Need - low weight

<Internals\\Focus Group 2> - § 1 reference coded [0,27% Coverage]

Reference 1 - 0,27% Coverage

RR: Aerodynamics and weight as well? If you are going in really dirty..

<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,62% Coverage]

Reference 1 - 0,62% Coverage

Basecoat is average using about 2.9 kilograms. Primer is probably less and clear coat is a little bit more. Of course, that is something that, yeah, everybody is being pushed towards, less weight, less weight, less weight.

Name: Need - material storage condisiton

<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,99% Coverage]

Reference 1 - 0,99% Coverage

I mean, it's rough, but it's if you say "well there's no way of doing it", then the supplier says "OK, we can work with it". But we need to have time, money, we need to try some materials. Is it going to be worthwhile? How much are we going to sell? If it's 400 000kr a year and we need to invest 2 000 000, there's no market for it, why should they do it?

Name: Need - metallic feel

<Internals\\Focus Group 2> - § 1 reference coded [0,70% Coverage

Reference 1 - 0,70% Coverage

LM: I think the materials also, to not make it look plastic

ALL: yeah

LM: and that's a big part, also in the interior, that it shouldn't look plastic, it should feel more metallic

Name: Need - no bubbles

<Internals\\Focus Group 2> - § 1 reference coded [0,20% Coverage]

Reference 1 - 0,20% Coverage

RR: Will they result in some bubbles or some wrinkles

<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 2 references coded [0,50% Coverage]

Reference 1 - 0,06% Coverage

not being bubbly

Reference 2 - 0,44% Coverage

Having said that, we cannot have any bubbles or it should not look like a film - it should look like a paint

<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,40% Coverage]

Reference 1 - 0,40% Coverage
you need to put it on without any bubbles, imperfections, I mean anything with the foil will be visible. So [you need] the dust-free environment

Name: Need - no cheap, sticker feeling
<Internals\\Focus Group 2> - § 4 references coded [1,94% Coverage]
Reference 1 - 0,23% Coverage
LM: I think the materials also, to not make it look plastic
Reference 2 - 0,52% Coverage
If it has two colors and one is the original vehicle and the other is a film. And if the film looks plastic, I will never buy the car.
Reference 3 - 0,61% Coverage
LM: Like if you have a surface and you put the film only here, you shouldn't see the line between like.. 'Oh I can rip off here!'. Shouldn't be like a sticker.
Reference 4 - 0,57% Coverage
EJ: My first thought would be that it is plastic, maybe. But, maybe that's because I don't really know a lot about this. That'll be my first thought.
<Internals\\Focus Group Transcript> - § 2 references coded [2,82% Coverage]
Reference 1 - 1,53% Coverage
And I think also generally, a car is a prestige product. So the need and the want to have a personal expression, I think, is higher than other products. So it is a personal & prestige product and it should say a lot about you. You want it to say a lot about you.
Reference 2 - 1,29% Coverage
it looks like a sticker and if you feel that it is a sticker, take it off, it feels Cheap and you don't want it to be like that. It need to be high quality and look like something that is really incorporated with the car.
<Internals\\Interview with Anders Bergstrom - senior designer> - § 1 reference coded [8,08% Coverage]
Reference 1 - 8,08% Coverage
Usage of films tends to provide a feel of having 'Stickers' on the vehicle exterior which in turn could give a rather 'Cheap' feeling to the car owner. Hence it would be better to have a film developed and placed on the surfaces such that an ordinary customer is not able to recognise it.

Name: Need - no dirt around edges
<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 1 reference coded [1,83% Coverage]
Reference 1 - 1,83% Coverage
I have seen some vehicles have this protection tape on it and from PQ perspective it should really be as invisible as possible. Because maybe it looks OK when the car is brand new, but after you've driven 1K or something on the road, then you get this dirt around the tape, which then makes it really obvious that there is a tape and you think if there has been a mistake that they were trying to cover, or the shape of the car that allows stone chipping.
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,99% Coverage]
Reference 1 - 0,99% Coverage
if you have dirt particles on it and you're trying to be really really accurate, and any little imperfection, you'll see it. Of course it has to do with the colour combination also - white over black, black over white. You see it more than in black over dark-blue or something. So that comes in as well - what is the target, what is the colour combination.

Name: Need - no stains when washing in sun
<Internals\\Focus Group 2> - § 1 reference coded [0,61% Coverage]
Reference 1 - 0,61% Coverage
EJ: I faced a problem. I have a black car and when I tried to wash it in the sun, it usually gets a lot of ugly stains because the water there dries quickly.

Name: Need - non-toxic films
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [1,26% Coverage]
Reference 1 - 1,26% Coverage
So that is something from the very beginning they also need to report on, because, no company could afford being sued for people working in an area where they are working in for several hours. They work in it for about 8-10 hours. So, not saying that nobody is making it, but that is really one big issue in China that, because they are so great with copy and paste, we may not with paint but other items where they said "Oh this is something easier!"

Name: Need - opaque coat
<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 1 reference coded [0,05% Coverage]
Reference 1 - 0,05% Coverage
see-through
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,92% Coverage]
Reference 1 - 0,92% Coverage
It's more or less like if you have a black piece/wall and you try to put white on it, how much white is needed to cover the black wall. When we do paint development and would be the same on colored foils, how transparent is it? Is the bottom color still showing through? If I use a red foil on a white car, it could look pink.

Name: Need - PPF invisible
<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 1 reference coded [1,83% Coverage]
Reference 1 - 1,83% Coverage
I have seen some vehicles have this protection tape on it and from PQ perspective it should really be as invisible as possible. Because maybe it looks OK when the car is brand new, but after you've driven 1K or something on the road, then you get this dirt around the tape, which then makes it really obvious that there is a tape and you think if there has been a mistake that they were trying to cover, or the shape of the car that allows stone chipping.

Name: Need - production dependent on Volvo
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,73% Coverage]
Reference 1 - 0,73% Coverage
it's a copy from Volvo - because of course the first vehicle is under Volvo-roof so it's not going to work to have on paint lines two different clear coats, because of the demand of filling systems, containers really. Again, it's coming back to square footage.

Name: Need - production ergonomics
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [1,80% Coverage]
Reference 1 - 1,80% Coverage
If you think about putting a foil from the front of the car across the stripe on the roof and on the trunk, how can I access it without climbing? It's also important. And in general Chinese are not very tall. And we have a project right now with CX11 on an existing line, because the car was not made for 2-tone. We're still trying to find out "OK, where can we do this step on the line?" because it was not planned. Actually we had this realizaiton when someone said "maybe we should only use taller people to do this kind of working step". You cannot do this, you cannot say "for this working step I need somebody who's at least 1,70m or so",

Name: Need - production tooling
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [1,03% Coverage]
Reference 1 - 1,03% Coverage
Do I need some tooling? If we want 2-tone, we're going to use specific tooling. Do I need to have (it is also money) fixtures to hold the foil? How do you precisely, each time, without having +/-2mm variance, (because if it's supposed to be like this, nobody wants to have it like that) to make sure that it's exact each time from person to person, from shift to shift.

Name: Need - production training
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [1,03% Coverage]
Reference 1 - 1,03% Coverage
Do I need some tooling? If we want 2-tone, we're going to use specific tooling. Do I need to have (it is also money) fixtures to hold the foil? How do you precisely, each time, without having +/-2mm variance, (because if it's supposed to be like this, nobody wants to have it like that) to make sure that it's exact each time from person to person, from shift to shift.

Name: Need - removal without marks
<Internals\\Focus Group Transcript> - § 1 reference coded [0,97% Coverage]
Reference 1 - 0,97% Coverage
BO: How about glue rests if the film has been on a car for a couple of years and there has been 100 degrees on the hood, will you be able to get rid of the glue rests?
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,31% Coverage]
Reference 1 - 0,31% Coverage
So we need to make sure that the tape is not leaving any color or appearance, something you can see afterwards
<Internals\\User Interviews- Ray Zhang> - § 1 reference coded [0,59% Coverage]
Reference 1 - 0,59% Coverage
Will it damage the surface of my car?

Name: Need - resist humidity
<Internals\\Focus Group Transcript> - § 1 reference coded [1,96% Coverage]
Reference 1 - 1,96% Coverage
JT: Of course, we need to fulfill requirements for humidity, sound, aging and things like that. That is a little risky. And we also talk about if it will be scratch resistant; if it will be glossy/ matte maybe, for example. Also appearance changing during the time, say. Also I think the application in our production. How do we apply it?
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,80% Coverage]
Reference 1 - 0,80% Coverage
We had that situation in Alabama where we had a plastic part on a metal and this was never tested in the specification, and in the Alabama sun at 45-50 degrees outside, high humidity, the plastic parts slowly came off, and it was observed that we'd need to come up with new testing then

Name: Need - resist temperature
<Internals\\Focus Group 2> - § 1 reference coded [0,98% Coverage]
Reference 1 - 0,98% Coverage
Still, if the engine overheats, the outer paint does not get damaged, run-off or fade-off , something like that. But will the films hold the same? That would be it. Technically there could be many questions, but you should also add that part into it.
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,80% Coverage]
Reference 1 - 0,80% Coverage
We had that situation in Alabama where we had a plastic part on a metal and this was never tested in the specification, and in the Alabama sun at 45-50 degrees outside, high humidity, the plastic parts slowly came off, and it was observed that we'd need to come up with new testing then
<Internals\\Marcus Schill - Bumpers and Claddings systm manager> - § 1 reference coded [0,43% Coverage]
Reference 1 - 0,43% Coverage
If you talk about temperature, it's -30 up to +85 degrees

Name: Need - same surface quality on plastic and metal
<Internals\\Focus Group 2> - § 1 reference coded [2,31% Coverage]
Reference 1 - 2,31% Coverage
What happens is: you're trying to get as much off [dirt] with the water as you can, but then there is a small residue remaining of either soap or dirt itself. And then it's really hard to get it off and you can feel that when you wipe the metal part and then you come towards the plastic part, the paint is actually not exactly as good as the other one, so you sort of, don't know if it is clean or it is just how it is. Especially on an older car which I have, and which is a bit sort of beaten with all the Indian road chips that sort of hit it, so it's a bit tough to clean know if it is clean.

Name: Need - smooth edge
<Internals\\Focus Group 2> - § 1 reference coded [0,61% Coverage]
Reference 1 - 0,61% Coverage
LM: Like if you have a surface and you put the film only here, you shouldn't see the line between like.. 'Oh I can rip off here!'. Shouldn't be like a sticker.
<Internals\\Focus Group Transcript> - § 1 reference coded [0,79% Coverage]
Reference 1 - 0,79% Coverage

If it is a smaller piece, maybe, it's the differences from paint to film and there's communication to your hand, maybe that's interesting

Name: Need - something unique
<Internals\\Focus Group Transcript> - § 1 reference coded [0,75% Coverage]
Reference 1 - 0,75% Coverage
Yeah, having the possibility of coming up with something new to have something that nobody else has, can be a good thing as well.
<Internals\\Interview with Anders Bergstrom - senior designer> - § 1 reference coded [2,24% Coverage]
Reference 1 - 2,24% Coverage
Films allow for application of patterns and effects (translucent coloured films)

Name: Need - stone chipping resistance
<Internals\\Focus Group 2> - § 1 reference coded [0,86% Coverage]
Reference 1 - 0,86% Coverage
VS: Yes, especially in India, you buy a brand new car and you go behind a truck and [showing shooting at him]. It's like getting shot by like 15 mobsters. So yeah, it's been a big problem, and that's why we got a clear bra.
<Internals\\Interview with Emelie Sundqvist - Perceived Quality> - § 2 references coded [1,09% Coverage]
Reference 1 - 0,44% Coverage
Defects in the paint, for example stone-chipping could happen and also it can come in dirt when you paint it
Reference 2 - 0,66% Coverage
Because now… I'm speaking a little bit for design, but now they are a bit locked in that "OK we cannot go out so much because then it's a risk for stone chipping"

Name: Need - UV stability
<Internals\\Focus Group Transcript> - § 2 references coded [0,17% Coverage]
Reference 1 - 0,16% Coverage
It needs to be UV resistant
Reference 2 - 0,01% Coverage
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 2 references coded [1,69% Coverage]
Reference 1 - 0,89% Coverage
UV stability, changing the colour after 1 year, 2 years, and the other one is clearly the adhesion. You know, when there\s this high-pressure washer, the OEMs have these tests where there is a panel, there's actually a cross, and they put damage to it; it is extreme. And if you want you can test every system not right.
Reference 2 - 0,80% Coverage
We had that situation in Alabama where we had a plastic part on a metal and this was never tested in the specification, and in the Alabama sun at 45-50 degrees outside, high humidity, the plastic parts slowly came off, and it was observed that we'd need to come up with new testing then

Name: Need - white should look like arctic white from Volvo
<Internals\\Focus Group 2> - § 1 reference coded [0,24% Coverage]
Reference 1 - 0,24% Coverage
VS: If you know there's this "arctic white" that Volvos have.

Name: Need for automation
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 1 reference coded [0,20% Coverage]
Reference 1 - 0,20% Coverage
I mean if you spray by hand a car in Europe, you're not going to sell it.

Name: Need for tests on production line
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 4 references coded [2,98% Coverage]
Reference 1 - 0,46% Coverage
somewhere where the application is intended to be. And it is in a whole automotive and other of course markets - you test but you cannot replace it with reality tests
Reference 2 - 0,26% Coverage
on an object which is not moving, and then imagine someone that has to do it under pressure.
Reference 3 - 0,88% Coverage
In Ci Xi, China, they call it pilot paint line but it's not really a pilot paint line because it's all a production line, but it's all manual. Manual spraying, not robot at all. So you cannot really test things in advance or check jobs per hour until you really come on line. Does that answer your question somewhat?
Reference 4 - 1,38% Coverage
Yeah, yeah, yeah. Basically, there are some pre-testing and lab testing that should ensure that the paint that is being sent from the supplier to the test labs here, nothing in this case, Volvo. Gothenburg. And if they are spraying it, and if we agree upon some test, it has to be done basically, there is a testing and then of course, nothing is going to be finalised until stuff is tested from the manufacturing plant itself. So then, online panels are being painted and sent again for testing.

Name: Problem - film application time
<Internals\\Interview with Silke Krook-Suhr - paint engineer> - § 3 references coded [0,59% Coverage]
Reference 1 - 0,04% Coverage
To do it faster
Reference 2 - 0,33% Coverage
Right now for each 2-tone car we're taking one regular car away because a 2-tone has to gone through a paint line twice.
Reference 3 - 0,21% Coverage
Paint right now is when it comes to large areas, probably little bit faster.

B

Appendix - Complete specification table

This appendix shows the complete specification, which should be used as an expansion to Tables 5.2 and 5.3 The target values and test methods are proposals only, need further verification. Also, test values which are of lower certainty, are marked as proposed values with a star sign (*). Target values are hidden for proprietary reasons.

Table B.1: Complete list of needs. Statements market with (F) are assumed to be unfeasible.

Req. num.	Testing Method	Target Value - Mandatory (hidden)	Target Value -Desired (hidden)	Target value - Best (hidden)	Comments	Vehicle areas	Film type
1	Technology Assessment						Decorative; Protective
2	ASTM D3813/D3813 M				Test method to be developed possibly basing on standard ASTM D3813/D3813M		Decorative; Protective
3	ASTM D882				To avoid over/stretching during application		Decorative; Protective
4	ASTM D3330				To enable correction of mistakes during application. Values based on supplier data	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
5	User study						Decorative; Protective
6	Time study				Times may differ between components		Decorative; Protective
7	Assembly development						Decorative; Protective
8	Time Study						Decorative; Protective
9	Time study						Decorative; Protective

10	Cost Estimation			Decorative; Protective
11	Cost Estimation			Decorative; Protective
12	Cost Estimation	Values based on wholesale prices		Decorative; Protective
13	ASTM D2578	Attached test procedure for PE and PU only. Also possible: ASTM F22	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
14	TBD	Should be minimized so that film doesn't get hot on summer days		Decorative; Protective
15	ASTM D2842	Preferably high to maintain fresh look of exterior	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
16	VCS 1026,52749	Also, standard measurements by ISO 4287 ISO 4288. Values according to NOTE-TREG 31826779. May differ depending on gloss	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
17	TBD	Test should account for prolonged time of film staying on the surface	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective

18	TBD	Test should be developed with a supplier to measure the reduction of scratches on the surface after self-healing		Decorative; Protective
19	TBD	No method exists; a simple Yes/No would do	Decorative	Decorative; Protective
20	TBD	Based on Req. No. 707 in VCS 5751,59	Doors/Side panels; Hood/Trunk;; Mirrors; Bumpers;	Decorative; Protective
21	VCS 1024,369	Alternatively ASTM D2197	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
22	VCS 1026,52749	Method may have to be modified dto measure roughness of the edge. Also, standard measurements by ISO 4287 ISO 4288	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
23	TBD	So that dirt does not stick at the edges		Decorative; Protective
24	ASTM-D5458	Ideally, close to 0	Hood/Trunk; Roof; Mirrors; Bumpers;	Decorative; Protective

25	ASTM D1746 - 15	Should be fully opaque for human eye		Decorative
26	VCS 1026,5175	Values based on VCS 5751,59	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative
27	ASTM D 6988-13	Values based on commercially available product data		Decorative; Protective
28	Visual inspection		Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
29	VCS 1026,52729	Exact values depend on desired gloss properties	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative
30	ASTM D1746 - 15	Targets can be set based on ASTM D1746 - 15		Protective
31	VCS 1027,0519	Test method based on paints, may need modification	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
32	TBD			Decorative; Protective

33	VCS 1026,52749		Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
34	VCS 1026,52749			Protective
35	VCS 1024,7137	Alternatively tested by Ford DVM-0056-PA	Doors/Side panels; Hood/Trunk; Mirrors; Bumpers; Trim	Decorative; Protective
36	VCS 1026,81779	Chemical dependent and component-dependent	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
37	VCS 1024,7137	Alternatively tested by Ford DVM-0056-PA	Doors/Side panels; Hood/Trunk; Mirrors; Bumpers; Trim	Decorative; Protective
38	ASTM D7187		Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
39	VCS 1024,11419	To facilitate thermal and mechanical expansion. Values based on current product data		Decorative; Protective

40	VCS 1024,7136		Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
41	ASTM D-1709	Can be used as a reference to create the relevant standard		Decorative; Protective
42	ASTM D3654	Can be used as a reference to create the relevant standard. Values based on current product		Decorative; Protective
43	ISO-10354	Wedge rupture test or modified VCS 1029,54719 with water jet at acute angle	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
44	VCS 1029,54719	Wedge rupture test or modified VCS 1029,54719 with water jet at acute angle	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative; Protective
45	ASTM D7490			Decorative; Protective
46	Supplier's data			Decorative
47	Supplier's data			Decorative

48	Supplier's data	Target values dependent on plant conditions	Decorative; Protective
49	TBD	Several different aspects of colour changing could be taken into consideration	Decorative
50	ASTM D5930	Affecting the warm/cold feel of surface. Values to be developed basing on warmth perception tests	Decorative
51	ASTM D696 - 16	Exact test standard not found; use the given standard as reference	Decorative; Protective
52	Supplier data	Values based on current product	Decorative; Protective
53	Supplier data	Values based on current product	Decorative; Protective
54	ASTM D3363	To prevent easy scratching of surface at high temperatures	Decorative; Protective
55	VCS 1027,339	To maintain stable texture of surface	Decorative; Protective

56	VCS 1027,339; VCS 1026,52729	Test performed after light exposure i.e. VCS 1027,339		Decorative; Protective
57	VCS 1027,1449	Also VCS 1027,139; VCS 5715,1029	Doors/Side panels; Hood/Trunk; Roof;	Decorative; Protective
58	ASTM D570	Values based on current product data	Doors/Side panels; Hood/Trunk; Roof; Mirrors; Bumpers; Trim	Decorative
59	TBD			Decorative
60	TBD			Decorative; Protective
61	ASTM D2732 - 14	To be used as a reference		Decorative; Protective
62	ASTM D7133 - 16	May not be an exact standard; can be used as a baseline. Test performed after light exposure according to VCS 1027,339		Protective
63	VCS 5036, 5			Decorative; Protective
64	VCS 5036, 5			Decorative; Protective

65	ASTM D7309	Can be used as a baseline; not the exact standard		Decorative; Protective
66	Lifecycle Assessment			Decorative; Protective
67	VCS 5036, 5			Decorative; Protective
68	TBD	Tests should be performed to define impact of this factor on performance		Decorative; Protective
69	ISO 536	This standard is used for determining the grammage of Papers; could be modified to suit for films		Decorative; Protective
70	Supplier data			Decorative; Protective
71	ASTM D3330	To avoid the film dislodging by itself. or at small loads Values based on supplier data		Decorative; Protective
72	TBD	Especially areas exposed to engine heat	Hood/Trunk; Roof; Bumpers;	Decorative; Protective
73	ASTM D3330	Supported by cleavage strength test i.e. ISO 10354		Decorative; Protective

74	VCS 1026,5175	Test performed after light exposure i.e. VCS 1027,339	Decorative; Protective
75	ASTM F2226	Tests performed after exposure as stated in VCS 1027,3389. Additional tests may be needed, see VCS 5751,59, point 801	Decorative; Protective
76	VCS 1026,5175		Decorative; Protective
77	ASTM D3330	Surface needs to be prepared prior to test	Decorative; Protective

C

Appendix - Summary of House of Quality

This appendix contains the results of performing the QFD on the customer needs and requirements. Table C.1 shows the list of requirements with their weight ranks based on the number and strength of relationships they have with customer needs. Table C.2 lists the need statements with their corresponding ratings obtained through customer surveys.

Table C.1: List of requirements together with their corresponding weights based on relationships with needs.

Quality Characteristics (Requirements)	Minimize, Maximize, or Target	Max Rela- tionship	Requirem Weight	Relative Weight
Possibility of Automation	maximize	9	14,64	1,14%
Curling	minimize	1	1,50	0,12%
Young's modulus	minimize	3	10,26	0,80%
Peel-off adhesion	maximize	9	47,62	3,72%
Presence of characteristic feature	target	1	1,50	0,12%
Substrate preparation time	minimize	9	15,39	1,20%
Number of steps	minimize	3	5,13	0,40%
time of application	minimize	9	19,89	1,55%
Film preparation time	minimize	3	5,13	0,40%
Equipment Cost	minimize	3	4,50	0,35%
Consumables cost per hour	minimize	9	13,51	1,05%
Material cost per area	minimize	9	13,89	1,08%
Wetting	minimize	9	28,44	2,22%
Maximum Heat Absorption	minimize	9	14,14	1,10%
Stain resistance	maximize	9	34,28	2,67%
Surface texture	target	9	85,20	6,65%
Area of residue left	minimize	9	16,51	1,29%
Self-healing properties	target	9	22,27	1,74%
Ability of repair with DIY paint repair kits (decorative only)	target	3	5,00	0,39%
Polishing quality	maximize	3	5,00	0,39%
Scratch resistance	maximize	9	34,15	2,66%
Edge Roughness	minimize	9	38,78	3,03%
Presence of adhesive	target	9	16,51	1,29%
Cling adhesion	target	3	7,51	0,59%

Opacity	maximize	9	15,80	1,23%
Colour deviation	minimize	9	76,19	5,94%
Thickness	minimize	9	29,98	2,34%
Edge visibility	minimize	9	22,77	1,78%
Gloss	target	9	55,80	4,35%
Transmittance of protective film	maximize	9	15,39	1,20%
Presence of bubbles	target	9	18,02	1,41%
Features supporting bubble-free application	target	3	6,01	0,47%
Orange peel look	target	9	18,02	1,41%
Variation in surface roughness	minimize	9	11,63	0,91%
Rubbing wear resistance	maximize	9	16,89	1,32%
Reactivity with chemical substances	target	9	39,41	3,07%
Abrasion Resistance	maximize	9	16,89	1,32%
Nano-scratch resistance	maximize	9	16,89	1,32%
Elongation	target	9	23,52	1,83%
Stone chipping resistance	maximize	9	16,89	1,32%
Impact toughness	maximize	9	16,89	1,32%
Shear adhesion	maximize	9	15,39	1,20%
Edge adhesion	maximize	9	15,39	1,20%
Pressure adhesion	maximize	3	5,13	0,40%
Surface Energy	maximize	9	18,39	1,43%
Possibility to apply custom colour	target	9	14,64	1,14%
Printability	target	3	4,88	0,38%
Possible to store in production area	target	9	12,39	0,97%
Colour changing properties	target	9	9,76	0,76%
Thermal conductivity	target	9	14,39	1,12%
Thermal expansion coefficient	target	9	15,39	1,20%
Minimum operating temperature	target	9	15,39	1,20%
Maximum operating temperature	target	9	20,52	1,60%
Hardness	maximize	3	5,13	0,40%
Change in toughness per time	minimize	3	5,13	0,40%
Gloss loss over time	minimize	9	15,39	1,20%
Corrosion resistance	maximize	9	15,39	1,20%
Water absorption	maximize	9	29,23	2,28%
Air tightness	maximize	3	5,75	0,45%
Solubility in water	target	9	15,39	1,20%
Shrinkage	minimize	9	17,26	1,35%
Yellowing	minimize	9	18,02	1,41%
Presence of toxic substances	target	9	18,77	1,46%
Toxicity after disposal	target	9	18,77	1,46%
Flammability	target	9	18,77	1,46%
Percentage content of recyclable materials	maximize	9	16,51	1,29%
Presence of standard Toxic substances	target	9	16,89	1,32%
Friction drag coefficient	minimize	9	9,38	0,73%
Mass per area	minimize	9	13,14	1,02%
Usage of special or specific tools	target	3	3,50	0,27%

Table C.2: List of need ratings according to stakeholder surveys, together with weight of each need.

Need ID	Rating	Weight (%)	Need ID	Rating	Weight (%)
1.1	3,9	1,63	5.5	4,1	1,71
1.2	3,6	1,50	5.6	4,1	1,71
1.3	4,1	1,71	5.7	4,9	2,04
1.4	3,6	1,50	6.1	3,9	1,63
1.5	3,7	1,54	6.2	3,3	1,38
2.1	2,9	1,21	6.3	2,6	1,08
2.2	4,5	1,88	6.4	3,4	1,42
2.3	4,4	1,83	6.5	3,7	1,54
2.4	4	1,67	6.6	3,5	1,46
2.5	4,6	1,92	6.7	2,9	1,21
2.6	4,4	1,83	7.1	4,1	1,71
2.7	3,9	1,63	7.2	4,1	1,71
2.8	3,1	1,29	7.3	4,1	1,71
3.1	3,7	1,54	7.4	4,1	1,71
3.2	4	1,67	7.5	4,1	1,71
3.3	4,1	1,71	7.6	4,6	1,92
3.4	4,7	1,96	7.7	4,1	1,71
3.5	4,5	1,88	7.8	4,5	1,88
3.6	4,1	1,71	7.9	4,6	1,92
4.1	4,8	2,00	7.10	4,7	1,96
4.2	4,5	1,88	7.11	4,8	2,00
4.3	4,8	2,00	8.1	5	2,09
4.4	2,5	1,04	8.2	5	2,09
4.5	3,1	1,29	8.3	4,4	1,83
4.6	4	1,67	8.4	4,5	1,88
4.7	4,7	1,96	9.1	2,5	1,04
5.1	4,5	1,88	9.2	3,5	1,46
5.2	4,5	1,88	10.1	2,8	1,17
5.3	4,9	2,04	10.2	2,5	1,04
5.4	4,5	1,88	10.3	2,8	1,17

D

Appendix: Validation checklist

This appendix presents the details of validation checklist used to scan the requirements specification for general defects. The checklist is based on the one proposed by Wiegers and Beatty (2013), and adjusted to the more general case.

Table D.1: Requirements validation checklist and results

Criterion	Result	Comments
Completeness		
Do the requirements address all known customer or system needs?	Yes	Requirements derived from needs.
Is any needed information missing? Is it identified as TBD?	Yes	Review of the complete specification
Do the requirements provide an adequate basis for design and test?	Yes/No	Some target values and test methods missing
Is the implementation priority of each requirement included?	Yes	By Kano model and requirement weights
Is each requirement in scope of the project?	Yes	Scope defined for general specification
Correctness		
Do any requirements conflict with or duplicate other requirements?	Yes/No	No duplication; some trade-offs impossible to avoid
Is each requirement written in clear, concise, unambiguous, grammatically correct language?	Yes	Required language limited. Metrics and units to avoid ambiguity
Is each requirement verifiable by testing, demonstration, review or analysis?	Yes/No	Verifiable by their metrics, but some test methods missing
Are the requirements technically feasible within known constraints?	Yes	Target values developed basing on existing product specifications
Quality attributes		
Are all usability, performance and safety features properly specified?	Yes	Division into value dimensions to ensure all main aspects are covered
Are other quality attributes documented and quantified?	Yes/No	Documented (listed) and quantified (assigned unit). Some targets missing.
Are all the quality requirements measurable?	Yes/No	Set metrics, some test methods missing
Organization & traceability		

Are the requirements organized in logical and accessible way?	Yes	Cross-referencing tables in report, searchable spreadsheet, division in groups
Are all cross references to other requirements and other documents correct?	Yes	Specification reviewed to ensure no references missing
Are all requirements written in consistent level of detail?	Yes	The value driver ->metric ->unit template was used for all of them
Is each requirement uniquely and correctly labeled?	Yes	Specification reviewed to check numbering
Is each requirement traced to its origin?	Yes	Cross referencing to stakeholder needs and from those to statements
Other issues		
Are all the business rules identified?	Yes	Numerous contacts with stakeholders