CHALMERS
UNIVERSITY OF TECHNOLOGY

Analysis of Attachment Techniques of Exterior Parts in Car Assembly

A Technical Evaluation

Master's thesis in Production Engineering

FILIP LARSSON
ANTON TENNBY

Department of Technology Management and Economics
CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2017, Report No. E 2017:028

Master's thesis E 2017:028

Analysis of Attachment Techniques of Exterior Parts in Car Assembly

A Technical Evaluation

FILIP LARSSON
ANTON TENNBY

Department of Technology Management and Economics
Chalmers University of Technology
Gothenburg, Sweden 2017

Analysis of Attachment Techniques of Exterior Parts in Car Assembly
A Technical Investigation
FILIP LARSSON
ANTON TENNBY

Master's Thesis E 2017:028

Supervisor: Håkan Thorsson, CEVT AB, Peter Almström, Department of Technology Management and Economics
Examiner: Peter Almström, Department of Technology Management and Economics
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: An illustration of exterior car body parts

Gothenburg, Sweden 2017

Abstract

This thesis has been carried out with the purpose to provide knowledge and help CEVT in future decision-making processes of selecting suitable attachment techniques for joining exterior car body parts in order to enable an efficient production of competitive cars.

The thesis has been performed at Chalmers University of Technology in cooperation with CEVT AB, a development centre for future cars of the Geely Group.

Companies active in the car industry uses different methods when fastening plastic exterior car body parts and standardized solution is yet to be found. Previous research of development is limited in this area and the issue comes and goes in accordance to automotive trends. Instead, current fastening methods are based mostly on practical experience and knowledge. On behalf of CEVT, an evaluation is made regarding which fastening method is preferable to use for attaching exterior car body parts with respect to cost, quality, productivity and ergonomics. This area is therefore of great interest to the car manufacturing industry in addition to its suppliers and customers. Hence, this thesis delivers:

- A complete analysis of the fastening methods used in car manufacturing of exterior car body parts
- An evaluation matrix that treats qualitative data
- A cost model tool designed to help CEVT compare investments and return rate of the fastening methods
- Guidelines regarding design aspects and common quality issues for the fastening methods

The course of this thesis is based on interviews with suppliers and experts in combination with study visits at Volvo Car's production plant as well as technical workshops. The results of this thesis shows that a majority of today's car manufacturers uses mechanical attachments for joining exterior car body parts and only a minority group of pioneers combines mechanical attachments with adhesive tape for wheel fender flare extensions. The process mapping and time studies shows that adhesive taping is a more complex and time demanding process in production when compared to snap-fit fasteners. The study has shown that it is not about what fastening method to use, it is about how to design for the right application. The use of immature methods is a symptom of a larger, organizational problem caused by late changes, which should be further explored.

Keywords: Adhesive tape, Snap-fit fastener, Exterior, Automotive, Fender flare, Wheel Arch Extension (WAE), Manufacturing engineering, Manufacturing cost, Evaluation matrix, MTM-SAM

Acknowledgements

First and foremost, we would like to place great thanks to our supervisor Håkan Thorsson at CEVT AB, Department of Manufacturing Engineering, for his effort and commitment throughout this project, and our examiner and supervisor Peter Almström from Chalmers University of Technology for his valuable guidance. The interviews, being a foundation of this study, would not have been possible without the interest and involvement of automotive suppliers and experts. We would therefore like to thank all involved interviewees for their committed time and effort for this study. As the study visit has been a major foundation for our understanding of the current situation in car manufacturing, we would like to place special thanks to Marcus Jonasson at Volvo Cars for his invaluable effort in giving us a plant tour and answering questions. Furthermore, we would like to thank all employees at the department of Manufacturing Engineering at CEVT who have supported and helped us in our work.

Filip Larsson & Anton Tennby, Gothenburg, June 2017

Contents

1 Introduction **2**
1.1 Background 2
1.2 Problem definition 3
1.2.1 Product flow 3
1.3 Purpose 4
1.4 Objectives 4
1.5 Research questions 4
1.6 Delimitations 5

2 Methodology **6**
2.1 Learning phase 6
2.1.1 Literature study 7
2.1.2 Quantitative data 7
2.1.3 Interviews 8
2.1.4 Observations and study visits 8
2.2 Identification phase 8
2.2.1 Process selection model 9
2.2.2 Research areas 10
2.2.3 Product groups 10
2.3 Evaluation phase 11
2.3.1 Evaluation matrix 12
2.3.2 Case study 12

3 Theory **13**
3.1 General theory 14
3.1.1 Adhesive tape 14
3.1.2 Mechanical bonding 18
3.1.3 Hybrid bonding 22
3.1.4 Testing and verification 22
3.2 Economy 23
3.2.1 Activity-Based Costing 25
3.3 Time 25
3.3.1 MTM-SAM 25
3.3.2 Basic activities 26
3.3.3 Supplementary activities 27
3.3.4 Repetitive activities 27

3.4 Quality . . . 28
3.4.1 Perceived quality . . . 28
3.4.2 PFMEA . . . 29
3.4.3 Ishikawa diagram . . . 30
3.5 Ergonomics . . . 30
3.5.1 Cognitive ergonomics . . . 31
3.5.2 Design for assembly (DFA) . . . 32
3.6 Evaluation matrix . . . 33
3.6.1 Engineering . . . 34
3.6.2 Production . . . 35
3.6.3 Final product . . . 36
3.6.4 After market . . . 37

4 Analysis **39**
4.1 Mapping of processes . . . 39
4.1.1 Function analysis . . . 39
4.1.2 Snap-fit process . . . 40
4.1.3 Adhesive tape process . . . 40
4.1.4 Hybrid process . . . 41
4.2 Competitor analysis . . . 41
4.2.1 Fender flare . . . 44
4.2.2 Door edge molding . . . 47
4.2.3 Rocker panel . . . 49
4.3 Economy . . . 51
4.4 Time . . . 55
4.5 Quality . . . 56
4.5.1 PFMEA . . . 56
4.5.2 Ishikawa diagram . . . 60
4.5.3 Perceived quality . . . 63
4.6 Ergonomics . . . 63
4.6.1 Cognitive ergonomics . . . 64
4.6.2 DFA - Product complexity . . . 64
4.7 Evaluation matrix . . . 65
4.7.1 Engineering . . . 70
4.7.2 Production . . . 70
4.7.3 Final product . . . 71
4.7.4 After market . . . 72
4.7.5 Summary . . . 73

5 Discussion **74**
5.1 Methodology . . . 74
5.2 Competitor analysis . . . 75
5.3 Cost model . . . 76
5.4 Time study . . . 77
5.5 Quality . . . 78
5.6 Ergonomics . . . 81
5.7 Evaluation Matrix . . . 81

5.8 Societal, ethical and ecological issues 82
5.9 Suggestions on further research 83

6 Conclusions 86

7 Guidelines 88
7.1 Adhesive bonding 88
7.2 Mechanical bonding 89

References 90

A Interviews I
A.1 Lars Ahlstrand, Tesa AB I
A.1.1 Tape characteristics I
A.1.2 Application requirements II
A.1.3 Tools and aids III
A.1.4 Service and wear III
A.1.5 Advantages and disadvantages III
A.1.6 Summary IV
A.2 Uno Andersson, 3M IV
A.2.1 Acrylic foam tapes IV
A.2.2 Applications V
A.2.3 Quality assurance V
A.2.4 Summary VI
A.3 Marcus Jonasson, VCC VI
A.3.1 Today's situation VI
A.3.2 Tape project VII
A.3.3 Positioning VII
A.3.4 The detail VII
A.3.5 Serviceability VII
A.3.6 Summary VIII
A.4 Heléne Karlsson, Swerea IVF VIII
A.4.1 Innovative solutions IX
A.4.2 Technical aspects IX
A.4.3 Tape testing X
A.4.4 Summary X
A.5 Johan Jacobsson, Din Bil XI
A.6 Anders Bergman, Plastal XI
A.6.1 Analyze XII
A.6.2 Process break-down XII
A.6.3 Testing and design XII
A.6.4 Designs XIII
A.6.5 Cost XIII
A.7 Mikael Torslund & Niklas Hansson, ITW XIII
A.7.1 Snap-fit technology XIV
A.7.2 Common issues XV
A.7.3 Ergonomics XVI

A.7.4 Design . . . XVI
A.7.5 Material and application surface . . . XVII
A.7.6 Cost . . . XVII
A.7.7 Summary . . . XVII
A.8 Johan Håkansson, VCC . . . XVIII
A.8.1 General prerequisites . . . XVIII
A.8.2 Common issues . . . XVIII
A.8.3 Design and manufacturing engineering . . . XIX
A.8.4 Primer . . . XIX
A.8.5 After market feedback . . . XIX
A.8.6 Summary . . . XX

B Study visits **XXI**
B.1 Tuve skadecenter workshop . . . XXI
B.1.1 Common issues . . . XXI
B.1.2 Serviceability . . . XXII
B.1.3 Workshop case . . . XXII

C MTM-SAM **XXIV**

1 Introduction

This holds as a final report for the master thesis project, as a part of our education in Production Engineering at Chalmers University of Technology at the Department of Technology Management and Economics. The project work is intended to exploit our knowledge acquired in our education by delivering a satisfying solution to the stakeholders in addition to a learning experience for ourselves. The project intends 30 credits and was initiated by the project group together with CEVT, at the Manufacturing Engineering department.

1.1 Background

China Euro Vehicle Technology (CEVT) is a development centre for future cars of the Geely Group and covers all aspects of passenger car development - from total architecture to top hat engineering (CEVT, 2016). Manufacturing Engineering is responsible to make sure that R&D's design solutions are possible to manufacture and produce in an efficient way. Considering this, an interest in exploring the use of different techniques in car body part attachment has risen.

A priority for automotive engineers is to develop cars with reduced weight to have the ability to decrease fuel consumption (de Wit and Poulis, 2012). Lowering the weight of the car is done through out all development phases. Making structural parts lighter, while still meeting the quality requirements, forces the engineer to use stronger steels or even lighter materials. However, joining them together is a key issue in the design process (LeBacq et al., 2001) and pushes the engineers to its limits in terms of meeting the requirements and develop new technologies.

Attaching exterior and interior parts in car assembly can be done in several ways, yet the common way today is to join with a mechanical attachment such as snap-fit or screw fasteners. These mechanical attachment techniques are reliable and quality assured with industrial approval. However, the mechanical techniques requires drilling, punching holes or putting weld studs to the car body with high precision and productivity, which is costly and time consuming. An alternative technique is adhesive taping which can be used as a substitute for attaching exterior parts to the car body and enables a less restrained design of the part. Nevertheless, adhesive taping has higher requirements on the attachment execution and it is harder to verify the quality afterwards.

Besides from the costs associated with the joining methods, there are other factors such as robustness and flexibility that are important. A highly efficient production line relies strongly on the speed and effectiveness of the joining technique (de Wit and Poulis, 2012). For any product, components are joined together in order to achieve a function, or to achieve structural efficiency, which includes optimizing the material selection and utilization, and minimizing the cost of the manufacture and assembly (Sodhi et al., 1999).

The thesis results will contribute to the production of future CEVT cars and the study will include analysis of existing cars from various manufacturers to enable a broader understanding of the issue.

1.2 Problem definition

The understanding of different joining techniques is of high importance for a car producer. The problem is that CEVT takes decisions on fastening techniques with insufficient knowledge and understanding because of no existing in-house production. Consequently, there is an imminent risk that quality, cost and competitiveness looses ground.

1.2.1 Product flow

To understand the problem and its connection to the whole value chain, the product flow of the car is explained in Figure 1.1. The product flow covers all processes that are affected by the attachment of car body parts. First, the part is designed by R&D. Second, the part design is verified by Manufacturing Engineering in terms of producibility. These two processes are interconnected in the organization and works as one unit which will be referred to as the engineering phase henceforth. Third, the part which is delivered by the supplier is attached to the car with an attachment technique in the production phase. Fourth, in the final product phase, the final product can be delivered to customers with certain requirement fulfillment and characteristics. Finally, the car is in need of service and reparations in the after market phase.

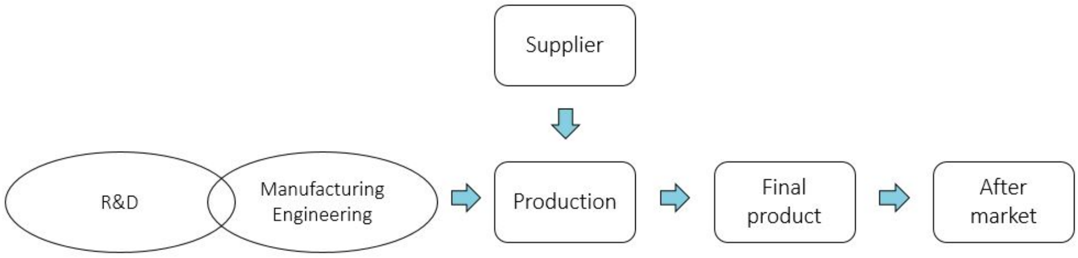

Figure 1.1: Product flow

1.3 Purpose

The purpose of this thesis is to provide knowledge to help CEVT in the decision-making process of selecting suitable attachment techniques for joining exterior car body parts in order to enable an efficient production of competitive cars.

1.4 Objectives

The aim for this project is to produce quantifiable and qualitative results that can be used in the decision-making process for choosing the best suited technique for a set of specific cases in future attachment of exterior car body parts. In order to fulfill this aim, the project have worked towards the following objectives:

- Provide knowledge of mechanical attachments and adhesive taping for exterior car body parts
- Develop a model for evaluating mechanical attachments and adhesive taping of exterior car body parts
- Compare mechanical attachment against adhesive taping for a set of exterior car body parts

1.5 Research questions

Research questions force you to condense and focus on what is really important in the project. Without any, or poorly formulated, research questions the research will lead to worsened results (Bryman and Bell, 2015). Denscombe (2014) provides a set of types of research question, in which some have been derived from to form the research questions in this project; evaluating a phenomenon, describing a phenomenon, comparison, and developing good practice.

Connected to the first objective with the incentive of exploring the usage of mechanical attachment techniques and adhesive taping in automotive industry, the first research question can be defined as:

- *RQ1* - How are mechanical attachments and adhesive taping used for joining exterior car body parts in car manufacturing?

Directly connected to the second objective, the second research question can be formulated as:

- *RQ2* - How can the evaluation of mechanical attachment and adhesive taping in car manufacturing be modeled?

Derived from the second research question, the third research question is defined as:

- *RQ3* - For a defined case, what are the strengths and weaknesses with mechanical attachments and adhesive taping?

When the evaluation model is developed with relevant criteria, the final research question remains:

- *RQ4* - What are the prerequisites to ensure a successful joining process of exterior car body parts?

1.6 Delimitations

In collaboration with the stakeholders, a set of delimitations are defined to strengthen the scope. Thus, this project will not cover:

- Non-plastic exterior parts
- Non-frequently used attachment techniques
- Other adhesive techniques besides adhesive taping
- More than a defined set of car models and plastic exterior product groups

2

Methodology

A triangulated approach was adopted to ensure the project's validity and worked as a foundation for the work procedure. The combination of literature, qualitative and quantitative data will ensure a valid investigation with the aim to develop credible results that can be used for future research (Berlin and Adams, 2015).

Bryman and Bell (2015) defines a framework for research including literature review, concepts and theories, data collection, and deduction, which have, in combination with previous experiences in project work, formed the methodology used in this thesis. The project work followed a dedicated methodology process, presented in Figure 2.1, to reach the objectives. It consists of three separate phases explained below, where each phase serves as a basis for its successor. These phases followed an iterative approach and some parts of the phases re-appeared in later stages.

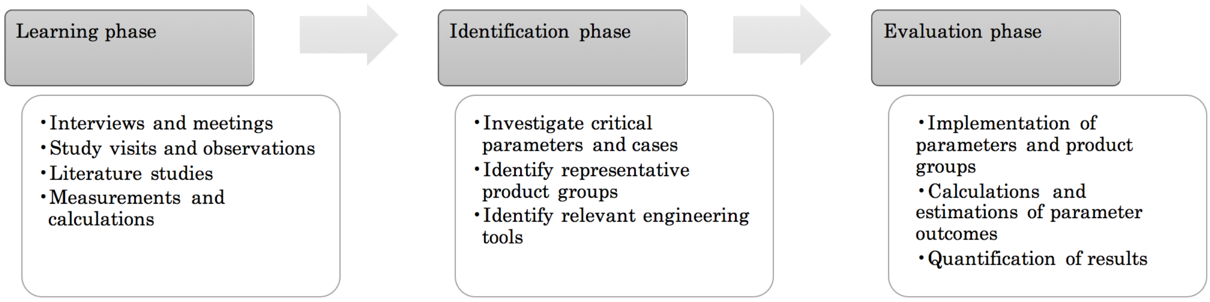

Figure 2.1: Methodology process

2.1 Learning phase

The first step in Figure 2.1 is to learn and develop an understanding of the problem in a structured way. The primary objective in this stage is to collect data of the attachment techniques and exploit why certain techniques are used in a set of scenarios. The methodology of learning and collecting data will be done through interviews and meetings, study visits and observations as well as literature studies.

Interviews and meetings will be done together with customers, suppliers, operators, managers and experts and will serve as an input to the data collection. Study visits or online contact with 3M, Tesa, Stokvis and Volvo Cars Torslanda plant will be carried out to make necessary observations. Time measurements, cost measurements, quality measurements and calculations will provide quantifiable data. Drawings, working instructions and requirement specifications for relevant articles will work as data input to the analysis.

2.1.1 Literature study

Existing literature represents an important element in all research (Bryman and Bell, 2015). A thorough literature study was conducted to allocate previous research knowledge within the subject and is presented in the theory section of the report. The literature study was performed with a wider scope than the actual project scope, as other mechanisms and conclusions are important to understand the issue from a holistic point of view. The literature study was performed with different search engines in order to get a wider range of results. Scopus, Web of Science and Google Scholar were mainly the databases used for the literature study. The importance of using the right keywords for the search is crucial for the result. The main keywords used in different combinations were adhesive, tape, mechanical, snap-fit, fastener, automotive, industry, process, selection, evaluation, joining, attach, bonding, method, and technique.

To filter out what hits that were interesting enough, the titles were used as a first sorting step. If the article seemed to be helpful for the scope, the abstract and conclusion were read to filter out even more. If further interest raised, the whole article was read.

2.1.2 Quantitative data

"Every researcher can and should use numbers in their research", (WFP Office Of Evaluation, 2017). Quantitative data can be used effectively without the need for complex statistical analysis and will provide a sufficient way of describing the profile of findings, exploring connections between parts of the data, and summarizing as well as displaying the findings (Denscombe, 2014). Descriptive statistics from supplier and manufacturers provided have been analyzed, and will serve as the quantitative part of the research. It has been particularly important to study data from other car manufacturers by analyzing reversed engineered cars available on the website A2MAC1.com (A2MAC1, 2017).

2.1.3 Interviews

As a part of the qualitative research, semi-structured interviews were performed to investigate attitudes and issues in detail (Denscombe, 2014). Denscombe (2014) describes that, in low-budget small-scale research projects, conducting interviews are best rewarded when the research are to explore complex phenomena, such as opinions, feelings, emotions, experiences, and privileged information. Which were the main objective with performing interviews.

The first three objectives (see section 1.4) regarding gaining knowledge about mechanical and adhesive attachment methods in car manufacturing, as well as why the different techniques are used, were investigated through interviews. Semi-structured interviews have been conducted with suppliers, researchers, experts, and engineers to understand the nature behind the joining techniques and why they are used. The interviewees were prepared in advance with a list of interview questions, giving them the opportunity to prepare.

2.1.4 Observations and study visits

Denscombe (2014) explains that there are two different types of observational research in social sciences, systematic and participant observation. Systematic observation is the study of interaction in settings and is normally linked to production of quantitative data and the use of statistical analysis (Denscombe, 2014). Participant observations is used to investigate lifestyles, cultures and beliefs of particular social groups, and is normally associated with qualitative data (Denscombe, 2014). For this thesis, the systematic observation type will be used to complement the data collection. The observations will mainly be performed at study visits to understand the nature behind the data analysis.

2.2 Identification phase

The second step, the identification phase is about identifying and investigating research areas, critical parameters and cases which is representative for this project's targets. Representative exterior car body part groups will work as a way of organizing dissimilarities and possible outcomes for different parts. A guiding set of research areas works as a way to organize relevant input and output data into understandable context. To assure a valid and thorough investigation, relevant engineering tools will be identified and later used to process data in the evaluation process. This phase is important to verify that the right scope is being followed in the later stages thus guaranteeing that the investigation derives accurate results. A process selection model is being followed throughout this phase to increase the validity and assurance of creating relevant results (LeBacq et al., 2001).

2.2.1 Process selection model

A general theoretical model for selecting appropriate processes has been derived and is explained in Fig 2.2, which was developed with inspiration from LeBacq et al. (2001). Unlike the work procedure, this model focuses on showing the relationship between the input data and how it is connected to the final process selection. In this structure, a technical basis is developed through identifying useful input data as in literature, analysis of technical regulations, and performing interviews and visits. This will form the set parameters for the evaluation phase, which will be quantified, ranked and sorted out according to importance. This will be complemented by identifying dedicated engineering tools and principles. These two information flows will together shape the evaluation model, whose output will deliver an indication on the most suitable process. The process selection model is meant to offer a holistic point of view of the project with a higher perspective to assure a value adding methodology throughout the project (Swift and Booker, 2013). Every step and input of the process selection model is further explained in the coming sections.

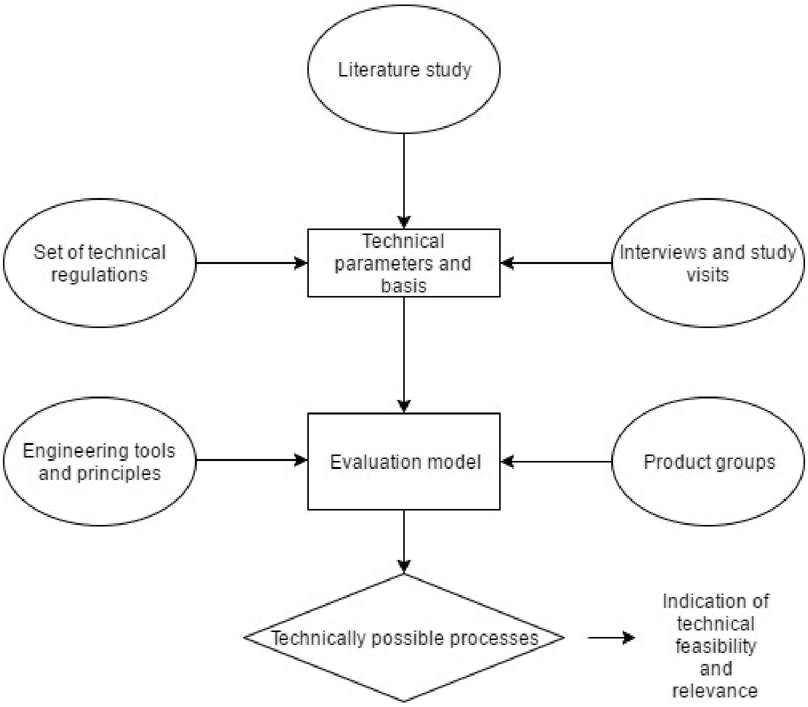

Figure 2.2: Process selection model

2.2.2 Research areas

A set of research areas to base the analysis on and use as a base for the project objectives and research questions is presented below. It is meant to guide and sort relevant data into different categories to facilitate comprehension of the project. Each research area includes certain deliveries and engineering tools used to create and assure relevant results with respect to the project scope.

The research areas were chosen after discussions together with stakeholders to strengthen the scope and the aim for the project. The research areas affects each other in different ways; time is closely connected to economy in terms of productivity in assembly, while ergonomics is connected to quality as a bad ergonomically situation negatively affects the quality of the end product.

- **Economy** - The economic aspect is important because of its direct connection to the manufacturer's profitability and thus a crucial part of the analysis. A cost model will be developed to cover the economy area with the function to deliver a pre-made cost model framework that covers the quantifiable data connected to the choice of attachment technique for car exterior body parts.

- **Time** - The time spent assembling using the different joining techniques in production is deeply connected to productivity. Time also influences the cost calculation results, and will function as a way of analyzing the process' feasibility and efficiency. The time study will be delivered with the aid of an Method Time Measurements (MTM) and Sequence-based Activity and Methods (SAM) analysis.

- **Quality** - Concepts like serviceability, repetitiveness, quality control, perceived quality and long-term durability for the final product will be considered since it profoundly influences the customer satisfaction of the final product. Quality is a broad concept that is affected by many circumstances and will be analysed with several engineering tools.

- **Ergonomics** - The physical and cognitive ergonomics issues related to assembling of the part in production will be concerned as sustainability aspect in terms of work environment.

2.2.3 Product groups

This section presents a set of product groups of plastic exterior car body parts delimited for this project. The product groups represents commonly used plastic exterior car body parts. The different joining methods that are used currently in the market will be studied through A2MAC1.com, provided by a company specialized in reversed engineering (A2MAC1, 2017).

Three commonly used product groups have been identified and are presented in Figure 2.3 & 2.4 (Tesa, 2016b). The first product group is named Rocker Panel and includes all plastic extensions attached at the bottom sides of the car. The second product group is named Fender Flare and includes all plastic extensions attached over the wheels. The third product group is named Door edge molding and is all plastic extensions attached at the bottom of the car doors.

Figure 2.3: Rocker panel

Figure 2.4: Fender flare

Figure 2.5: Door edge molding

2.3 Evaluation phase

The final step in the project is to deliver a decision making tool, in the form of an evaluation model. Based on estimations and calculations, a model for process selection will be developed. The purpose is to apply the model on critical scenarios identified in the previous phase, and to further on develop recommendations based on each attachment technique's strengths and weaknesses. To do this, a case study of a specific exterior car body part group will be performed together with an evaluation matrix that evaluates strengths and weaknesses for that specific case.

A cyclic approach to the evaluation phase is derived from the PDCA cycle (Johnson, 2002). The PDCA cycle is developed to enhance organizational continual process improvement. Figure 2.6 illustrates a cyclic approach to fortify a continuous mind-set that leads to an enhanced solution in the evaluation process (Johnson, 2002). The process is iterated until satisfied results are derived. First, from the two earlier phases, relevant parameters are implemented together with a set of product groups. These sources works as input data for the evaluation model. Second, a set of engineering tools is applied to process the input data and bring forth relevant insights. Third, a workshop with experienced professionals will be carried out to deepen the understanding and ensure a valid outcome. Fourth, the evaluation model is executed by assessing the parameters for different scenarios and product groups. Fifth, the result is analysed and quantified to enable comparisons between attachment techniques and product groups. The outcome is eventually followed up regarding validity and relevance with experienced professionals.

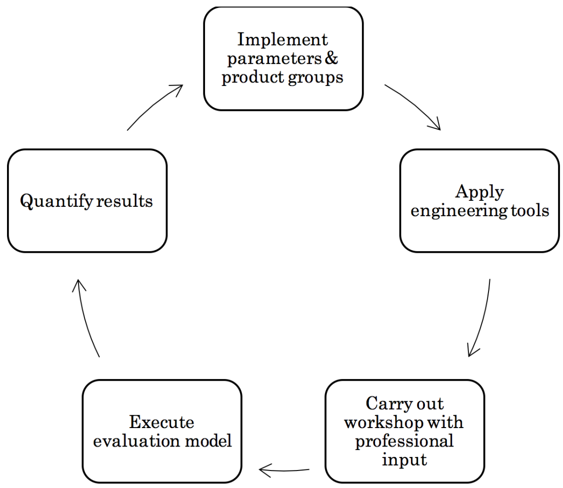

Figure 2.6: Evaluation cycle

2.3.1 Evaluation matrix

Derived from the research areas and product flow, an evaluation matrix is developed with categories matching the product flow. Thus, the matrix considers the value chain from the engineering phase to the after market phase, applied on a defined case. The purpose of the evaluation matrix is to clearly describe strengths and weaknesses for a certain case and product group. It is a framework that is possible to use for other cases and product groups as well for future research. The results of the matrix are used as decision making information for to facilitate difficult selections between attachment techniques for exterior car body parts.

2.3.2 Case study

A defined case is set to test and use the developed models created during the process and to enable comparison of figures and data. The case study focuses on one specific product group, fender flare, since it uses both mechanical fasteners and adhesive taping frequently by today's OEM's. That is to say, the fender flare has some uncertainties when it comes to the choice of attachment technique with no particular standard yet to be found.

3

Theory

The theory chapter explains the technical parameters included in the evaluation matrix and research areas from a theoretical point of view. It starts with general theory about adhesive tape and mechanical fasteners to develop a understanding of these two fastening concepts, including examples of both techniques. To create a structure, the technical parameters are divided into the different phases of the product flow, starting with the engineering phase which includes all activities performed before production, followed by the production phase where the car is actually assembled, followed by the final product phase including the technical characteristics connected to the performance of the end product, and ending with the after market phase where activities such as service is of high importance. Additionally, the project scope made out of the four different research areas explained as economy, time, quality and ergonomics with its corresponding analytical tools are presented theoretically.

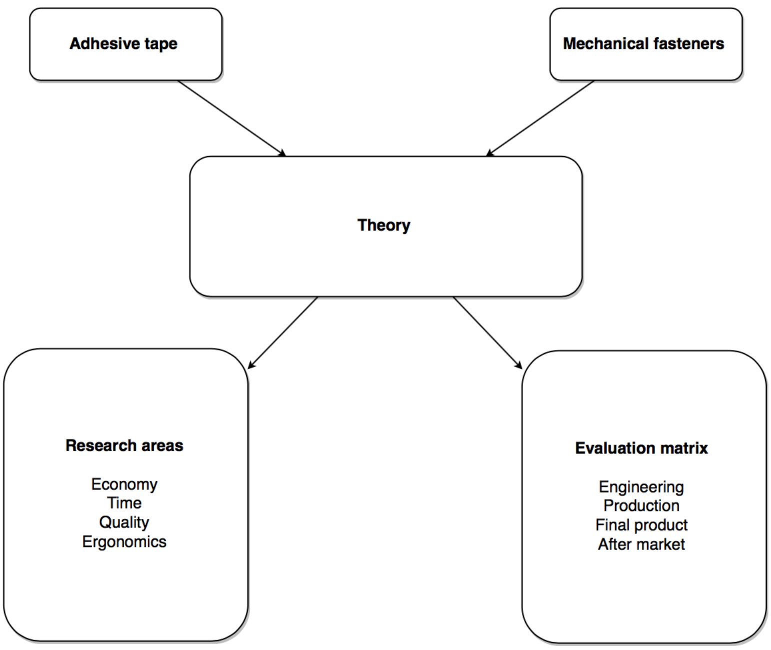

Figure 3.1: Theory model

3.1 General theory

As this thesis is about analysing adhesive taping and its characteristics against mechanical joining techniques in addition to a hybrid combination of both, the following sections will explain the theory behind the different methods. Hence, three different methods are used when joining exterior plastic extensions in automotive industry, see Figure 3.2; adhesive taping, mechanical bonding, or hybrid bonding. The most common adhesive tape used in automotive industry is the acrylic foam tape. For mechanical bonding, it is mainly snap-fit and screw fasteners that are used. The hybrid bonding is a combination of adhesive tape and mechanical bonding where both methods are being used simultaneously, which is a commonly used technique to attain multiple characteristics.

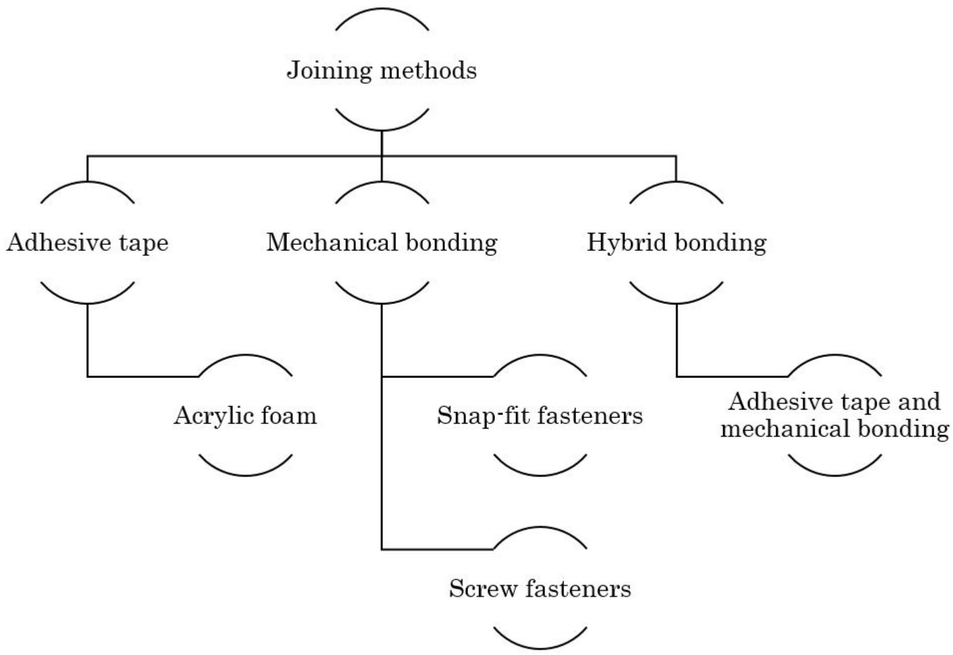

Figure 3.2: Joining methods

3.1.1 Adhesive tape

Adhesive tape consists of two main parts; backing and carrier together with or only an adhesive substance which alters in chemical disposition. The adhesive itself can be single core or multi core, consisting of different adhesives and combinations to get specific features (Karlsson, 2017). The adhesive tape's stickyness, called tackiness, is determined by the attraction between surfaces (surface energy), which are derived from the Van Der Waals forces (Karlsson, 2017). The energy surface varies greatly between different materials, hence it is very important to consider what material is to assure quality in industrial applications. As an example, glass with a surface energy of 250-500 mJ/m^2 which is higher than polypropylene's surface energy corresponding to 29 mJ/m^2 (Karlsson, 2017), and is more preferable to use for a good wet-out.

There are three main types of adhesive tape; foamed acrylic, filmic and non-woven (Tesa, 2016b). The first two variants a polymer carrier while the latter has a gas carrier. The adhesive tape thickness varies between 10 micrometer to 4 millimeters depending on the application, and for exterior plastic extensions the common thickness is 4 millimeters for visual reasons. It is preferable to use thicker adhesive tapes on rough surfaces while thinner are used for smooth surfaces. Thinner adhesive tape is suitable for designs with high weight requirements and no possibility of using mechanical attachments because of small components as in the electronics industry and mobile-phones (Tesa, 2016b).

Adhesive tape has been used in the automotive industry for decades and as technology is renewed, it is an everlasting investigation to find proper use of it. As of today, there are many applications for adhesive tape in the automotive industry such as exterior mirror, door sill, spoiler, tail light, sensors, chromed parts/lists, emblems, hood seal, license plate, grills, roof antenna, roof tails, roof edge seals, windshield frame, sunroof frame and seal (Tesa, 2016c).

Further on, an adhesive tape's technical behaviour can be explained by three technical characteristics that affects each other and results in a trade-off between them which is illustrated in the following triangle consisting of adhesion, cohesion and tackiness (3M, 2017). **Adhesion** is the tendency of two different materials to stick to each other. The adhesion effect is determined by the surface energy of the two materials and van Der Waals forces (Karlsson, 2017). **Cohesion** is the strength of the bond between two molecules sticking together. The initial adhesion is called **tackiness** and it represents the initial stickiness of a certain adhesive substance. There is usually a trade-off between these parameters (Ahlstrand, 2017), as no optimum can be achieved. The trade-off triangle is presented in Figure 3.3.

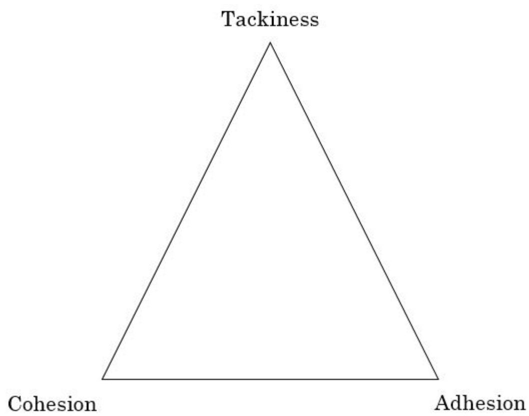

Figure 3.3: Trade-off triangle

Surface energy decides the strength of the adhesion (Karlsson, 2017). Surface treatment can raise the surface energy to improve adhesion if needed. A common type of surface treatment is to use a primer. The primer usually consists of poisonous substances as Ethylbenzene and Chlorobenzene among others (Karlsson, 2017). With this said, it is not appropriate to use primers in the production environment together with manual work. Another type of surface treatment to raise the surface energy is to flame the surface with a high temperature. Since primers are more or less poisonous and not used in today's car manufacturing plants besides from a few special exceptions, this project will not discuss the use of primer anymore than this.

It is important to consider different loads when designing for fastenings with adhesive tape. Adhesive tape has strengths and weaknesses regarding different types of loads. Figure 3.4 shows the most desirable to the least desirable type of load when it comes to the strength of adhesive tape. It is clear that peeling is the least desirable type of load for an adhesive tape, followed by cleavage. Compression and tension is fairly easy for the adhesive tape to handle while shear depends on the amount of force applied.

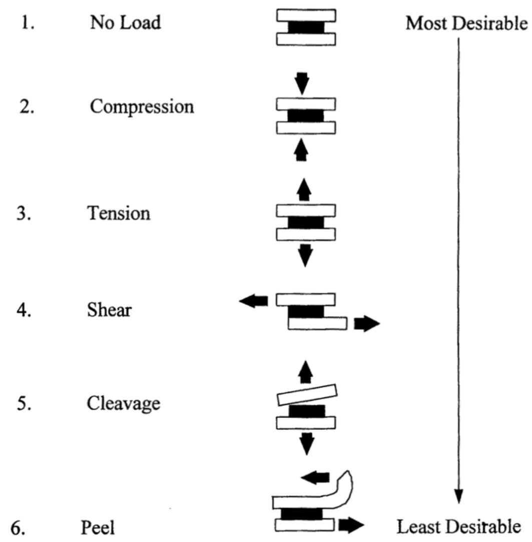

Figure 3.4: Loads

Acrylic foam tape

This project is delimited to only consider the acrylic foam tape, as it is the only adhesive tape used for plastic exterior parts in the automotive industry. It is the only tape that is cost efficient enough and at the same time passes the demanding requirements set by the car industry (3M, 2017). In the following section, the acrylic foam tape will be introduced and further explained, with corresponding application areas. After that, general characteristics and important concepts considering adhesive tape will be explained to fully exploit the theoretical base. Henceforth in this report, adhesive tape will refer to acrylic foam tape if nothing else is mentioned.

Acrylic foam tapes are developed to endure the extreme conditions that exists on the exterior of a car, which is why it is the most common adhesive tape used for car manufacturing. Acrylic foam tape consists of three layers visualized in 3.5, the outer layer is a Liner typically made of a polyethylene foil, the middle layer is made of an acrylate adhesive and the inner layer is called the acrylic foam core (3M, 2017). The structure of an acrylic foam tape is somewhat flexible due to its viscoelastic characteristics, the stresses can be optimally dissipated during temperature changes. It also absorbs tensions, vibrations and forces, thus minimizing rattling sounds with its characteristics similar to rubber (Karlsson, 2017).

Figure 3.5: Acrylic foam tape structure (3M, 2017)

Acrylic foam tape comes in many colors but the most common is black which is seen in Figure 3.6 since it blend into the environment and hide its appearance on exterior designs (3M, 2017). Acrylic foam tape has a high degree of flex, thus can be properly used in curvatures and corners. With a automatic water sealing, it keeps away dirt and moisture from the inner layers of the part that is attached effectively (3M, 2017).

Figure 3.6: Acrylic foam tape (3M, 2017)

The acrylic foam tape can be customized by changing thickness, density, adhesives, composition and liner to fit different applications (Chen et al., 2017). Technical features affected by the customization are listed below and goes from low to high. It is important to consider these features when customizing a certain acrylic foam tape for a specific application to reach a better result and to secure quality, see Table 3.1.

Initial strength	Low
Lasting strength	High
Shear	High
Temperature resistance	High
Solvent resistance	High
UV-light resistance	High
Aging resistance	High

Table 3.1: Acrylic foam tape features

When it comes to the application of acrylic foam tape, there are four main conditions that needs to be fully controlled (Tesa, 2016b) that are explained in the list below.

Application conditions

- **Pressure** - The bonding quality is directly dependent on the pressure applied on the adhesive tape to the substrate. First, a short and high pressure is required for an efficient contact and second, a leveled and timed pressure is needed to ensure wet-out which is dependent on the material.

- **Temperature** - The adhesive tape needs to be mounted and stored in the right temperature interval to work properly. The temperature of the part and the chassis have to be in the range of 15-35 °Cfor optimum wet-out.

- **Time** - There are requirements for a certain amount of pressure during a time frame to ensure a complete wet-out, which is about 10-20 seconds. The time required for complete adhesion may take up to 72 hours depending to the adhesive.

- **Surface condition** - The surface of the part and the chassis have to be dry and clean. Dust, fingerprints, oil, wax needs to be removed thoroughly to ensure wet-out. No humidity should exist on either surface or in the room.

3.1.2 Mechanical bonding

Carrying out an assembly of two parts is traditionally done by a mechanical binder such as screws, bolts, or rivets. Another commonly used mechanical binder for exterior car body parts in the automotive industry is the snap-fit fastener because of its low cost and high mounting speed in production. Snap-fit fasteners and screws are the industry approved mechanical fasteners for plastic exterior extensions so the following section will cover the theory behind particularly snap-fit and screw fasteners.

Mechanical fasteners

Screw fasteners are used in assembly as a mechanical binding, in the case of exterior car body parts it is usually used as additional fastening in places where it is not visible for increased durability, such as beneath the car or inside the wheel house. Due to visual reasons it is not the primary mechanical binding at visible positions, such as for plastic exterior body parts where snap-fit fasteners is the common variant.

A screw fastener is defined as a non-permanent fastening system. A non-permanent system can be separated without any special measures or damage to the base material, and is suitable for situations where regular dismantling is required (Swift and Booker, 2013). It has the purpose to fasten two or more parts of a system in a fixed position. Several variants of screws and bolts exists in terms of size, body, threads and head. Every variant is customized according the function requirements such as strength, dimensions, material and tolerances (Swift and Booker, 2013).

Figure 3.7: Screw fastener

The threads and holes are usually prepared, so the fastening can be performed efficient at the production line. A common quality problem with screw fasteners are to screw the fastener into the thread at an angle, which destroys the thread and has to be re-made. A normally used screw fastener variant can be seen in Figure 3.7.

Snap-fit fasteners

Integral features of the components to be joined are typically hooked tabs that lock into notches on the adjacent part to be assembled with the application of a certain force (Swift and Booker, 2013). The use of snap-fit integral attachments is usually a key element in the creation of plastic part designs that are easy to manufacture and assemble (Genc et al., 1998). It is a common solution to attach, for instance, exterior car body parts with snap-fit fasteners and is often used in high-volume production of plastic assemblies.

Snap-fit fasteners can be made of different kinds of plastic or rubber and are defined as a semi-permanent fastening system. A semi-permanent system can be dismantled on a limited number of occasions and may cause damage on the base material, and the separation may require an additional process, such as plastic deformation (Swift and Booker, 2013). Some snap-fit fasteners are designed in such a way that it is impossible to dismantle without plastic deformation because of high strength requirements and on the contrary, snap-fit fasteners with low strength requirements can be designed to dismantle very easily without plastic deformation. In the case of plastic deformation, snap-fit fasteners may have to be substituted before being used again (Swift and Booker, 2013).

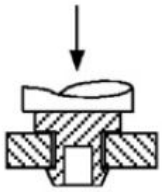

Figure 3.8: Snap-fit fastener

The snap-fits are usually delivered pre-assembled on the actual part, in this case the plastic car body extension coming from the supplier to the production line to enable shorter cycle times. The part is assembled through manually pressing onto the car body and can be verified when a snap sound and feeling occurs. Almost every snap-fit fastener is customized for its purpose and application so there are no actual standards defined and instead there are some categories that the snap-fit fasteners are divided into.

Four legged - The four legged snap-fit is a traditional fastener with good characteristics, however requires complete perpendicular mounting to avoid breaking. The four legged snap-fit fastener is visualized in Figure 3.9.

Figure 3.9: The four legged snap-fit fastener

Heart flex - The heart flex snap-fit, see Figure 3.10, is an ITW patented solution and was developed to allow not complete perpendicular mounting without breakage. However, the construction makes it more stable along the x axis compared to the y axis.

Figure 3.10: The heart flex snap-fit fastener

Triple heart flex - The triple heart flex, see Figure 3.11, is an evolution from the regular heart flex with more stable characteristics from a mechanical strength perspective. Three legs allows the snap-fit to be equally stable along the mounting plane.

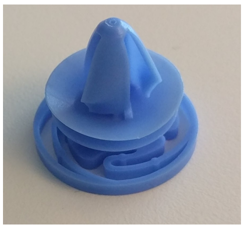

Figure 3.11: The triple heart flex snap-fit fastener

Christmas tree - The Christmas tree snap-fit is not considered as a traditional snap-fit fastener since one does not get the verification of the "feeling" of complete mounting (Torslund and Hansson, 2017) . The step-wise construction allows the snap-fit to be used over different geometries, but will not achieve the same level of quality as a regular snap-fit (Torslund and Hansson, 2017). The Christmas tree snap-fit fastener is presented in Figure 3.12.

Figure 3.12: The Christmas tree snap-fit fastener

Similar to adhesive tape, there are a some application conditions that are important to highlight.

Application conditions

Pressure - Unlike pressurising adhesive tape, snap-fit fasteners are not equally delicate. Pressure has to be applied until a snap sound appears, which verifies the application and complete attachment, and then the operation is done.

Temperature - There are no regulations regarding temperature for snap-fit fasteners. Although, most polymers becomes brittle in lower temperatures which increases the risk of plastic deformation.

Time - There are no specific regulations regarding application time for snap-fit fasteners, as the operation is verified by a snap sound in one instant.

Surface condition - There are no specific regulations regarding surface condition for snap-fit fasteners when compared to adhesive tape, except for the insertion hole that must be of correct dimensions and geometry to fit the design of the snap-fit fastener.

3.1.3 Hybrid bonding

The third and final joining option is to combine adhesive taping and mechanical bonding which is mostly done with acrylic foam tape and snap-fit fasteners/screws. This technique will have the combined characteristics of the individual joining methods. There are several purposes for using a hybrid bonding and one common situation is when the part has to be aligned against a surface, the tape is then added to prevent any type of gap between the part and surface. Another common situation is to add adhesive tape for sealing purposes against dirt and moisture. The application phase for a hybrid bonding needs to consider the application conditions for both techniques simultaneously which makes it a fairly complex solution.

Another type of hybrid bonding is when the front wheel fender flare is divided in two halves, one front part and one rear part. The rear half is attached with adhesive tape while the front half is snap-fit fastened. The purpose is to increase the serviceability aspect since the fender flare needs to be easily removed when the front/back bumper is in need of reparation. In this situation, the rear half is attached to the side of the car with tape while the front half is snap-fit fastened to the front bumper. It is the other way around for the rear wheel fender flare. As a result of this design, the snap-fit fastened part is easy to remove while the taped part remains attached to the side of the car during reparation.

3.1.4 Testing and verification

Testing and verification of the fastening technique is a prerequisite needed for the automotive industry. It is necessary to exploit the strengths and weaknesses of the joint and to enable repetitiveness and productivity during mass production. The chosen method must be stable and controllable thus testing and verification is vital to prove a certain quality.

Adhesive tape wet-out test It is possible to test the wet-out performance of adhesive tape in many ways, in this chapter a structured method created by 3M will be presented. This test is valid for acrylic foam tapes specifically and it requires removal of the tape, it is done in the following seven steps:

1. Clean surface area with alcohol/water mixture
2. Apply test ink directly on the surface and let it dry
3. Attach taped exterior part on the surface in the right conditions
4. Pressurize according to pressurizing requirements
5. Remove taped exterior part from the surface
6. Observe wet-out area and the percentage of test ink left on the surface
7. Identify critical contact areas and optimize design to maximize wet-out
8. Avoid entrapped air between the surface and the adhesive tape

Mechanical fastening test Mechanical fasteners provide a certain feeling and sound as a quality verification when being attached. It is a automatically quality assured method in this regard. It is also possible to test the quality of the joint afterwards by identifying the required pull-out force (disassembly force). It is a compromise between the assembly force and the disassembly force which has to be monitored closely. A higher assembly force gives a higher disassembly force and thus stronger resistances towards loads. However, an assembly force that is too high results in assembly and disassembly difficulties.

3.2 Economy

Costing refers to the procedure of accurately determining costs in advance of production (Freivalds and Niebel, 2009). Costs are the basis of operations within an organization and predetermining costs is necessary to set the right price for the product to ensure profitability (Freivalds and Niebel, 2009). As one objective regarding calculating the cost of the different joining methods analysed in this thesis, a cost model is essential for the results.

Dhillon (2012) defines a set of direct manufacturing costs in relation to maintenance, repair, labor, utility, material handling, raw material, royalties, direct overhead, laboratory charges, factory supplies and development. These cost factors can be sorted into direct material costs and direct labor costs, as well as indirect material costs and indirect labor costs.

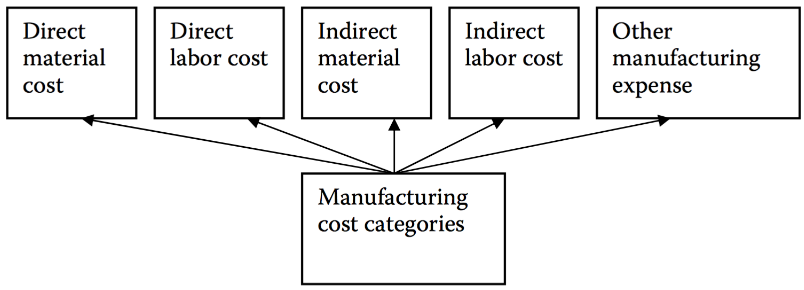

Figure 3.13: Cost factors

Another similar way to divide costs according to Freivalds and Niebel (2009) is to use the factors direct material costs, direct labor costs, factory expenses and general expenses. Further on as seen in the table below, Freivalds and Niebel (2009) divides direct material cost is into raw materials, purchased subcomponents, standard commercial items and subcontracted items. Direct labor refers to workers that are directly involved in the production (Freivalds and Niebel, 2009). Factory expenses includes indirect labor, tooling, machine, and power costs. General expenses are made of administration, rent, insurance, sales, and utilities (Freivalds and Niebel, 2009).

Table 3.2: Cost model (Freivalds and Niebel, 2009)

Cost category	Cost factor	Explanation
Direct costs	Direct material costs	Raw materials, purchased subcomponents, standard commercial items, and subcontracted items.
	Direct labor costs	Process time required to produce a product
Overhead costs	Factory expenses	Tooling, transportation, warehousing, maintenance, machine, and power costs
	General expenses	Accounting, administration, clerical, engineering, sales, etc.

To investigate the performance of a possible investment in terms of costs and generated income, a group of economical metrics is used (Dhillon, 2012). Net Present Value (NPV) represents the difference between the present value of future cash inflows and outflows. Weighted Average Cost of Capital (WACC) is a calculation of a company's cost of capital. Internal Rate of Return (IRR) measures the profitability of an investment, it is the discount rate that sets the NPV of all cash flows equal to zero. Pay back time is time it takes before an investments yields a positive return in cash flow. Time to break even is the time required for an investment to reach break even in terms of cash flows (Dhillon, 2012).

3.2.1 Activity-Based Costing

Activity-Base Costing (ABC) estimate the cost of resources used in organizational processes to produce outputs (Cooper and Kaplan, 1992). ABC attributes variable, fixed, and overhead costs directly to each product or service by using the activities required to produce the product as the means of allocation (Zandin, 2001). By using ABC, the cost of a product equals the cost of raw material plus the sum of all the activities needed to produce the product.

The difficulties using ABC is that the method requires the personnel to report their time allocation on different activities, which can cause obstacles in larger organizations. There is a simplified method available called Time-driven ABC (TDABC), where the management estimates the practical capacity compared to the theoretical capacity on a resource (Kaplan and Anderson, 2004). This factor is then multiplied with the cost per time supplying resources to the activities.

3.3 Time

The second research area is time which will be assessed through an MTM-SAM time study of the attachment process in production. The time study will be based on a fictive case made with professional assumptions due to the lack of possibilities to study a real situation.

3.3.1 MTM-SAM

MTM, or Methods-Time Measurement, is an analytical method used to describe manual assembly work in a distinct way, to facilitate a basis for improvement. The MTM time is an international standard for manual work performance (International MTM Directorate, 2004). The most used MTM-system in Sweden is the SAM, or Sequential Activity - and Methods Analysis (International MTM Directorate, 2004). The objective of MTM-SAM is to enable design work methods for high total productivity, document work methods in such way that they can be reproduced with the planned result at any time, and establish norm times based on documented work methods (Nordisk Produktivitet, 2017).

The SAM system norm performance level is the performance level most people are working at when carrying out manual tasks. Manual work basically consists of the movement of objects with the hands, in a planned procedure, to accomplish tasks with useful functions (International MTM Directorate, 2004).

The time unit in SAM is called a factor, where 1 hour is equal to 20,000 factors and 1 factor is equal to 5 TMU (Nordisk Produktivitet, 2017).

3.3.2 Basic activities

There are two basic activities that makes the foundation for the SAM system which makes it possible to analyse in a systematic way; GET and PUT.

GET - G
The GET motion is about gaining control over one or more objects with hand or fingers, and starts when the hand or fingers start their movement towards the object and ends when the hand or fingers have gained control over the object (International MTM Directorate, 2004).

The time for GET has two variables; movement distance and number of objects (International MTM Directorate, 2004). The movement distance is divided into the three distance classes 10, 45 and 80. The distance class 10 is for movement distances from 0 cm up to 10 cm. The distance class 45 is for movement distances from 10 cm up to 45 cm and the distance class 80 is for distances over 45 cm.

The number of objects is divided into the two scenarios get a SINGLE object (GS) and get a HANDFUL of objects (GH).

PUT - P
The PUT motion is about moving one or more objects to a final position with hand or fingers, and begins when the hand or fingers start the movement of the object towards final position and ends when the object have been placed in final position (International MTM Directorate, 2004). The final position is the position in which the objects are planned to be placed and is the primary function of the PUT activity.

The time for PUT has three variables; weight, movement distance and degree of position. The weight is divided into the two classes up to 5 kg and over 5 kg. For the movement distance, the SAM classes 10, 45 and 80 are used.

The degree of position required to place the object in to final position is divided into the two cases place DIRECTLY (PD) or with PRECISION (PP). PUT has two types of final position that must be defined before the degree of position is assigned; WITH or WITHOUT insertion.

3.3.3 Supplementary activities

Except from the basic activities, there are three supplementary activities in the SAM system; APPLY FORCE, STEP and BEND.

APPLY FORCE - AF
The APPLY FORCE activity is about applying force momentarily on an object, and begins with a short stop in the movement, a build up force, followed by the application of the force momentarily on the object.

STEP - S
The STEP activity is about moving the body, the leg or the foot, which are the three types of movements STEP includes.

As body movement, when a movement of distance class 80 is not long enough, the movement distance is supplemented with the total number of steps, including the last step before the GET activity or the PUT activity is carried out.

As leg movement, placing the foot on a pedal and activate it by moving the leg pivoted in the hip is one STEP. Moving the foot away from the pedal and place it on the floor is another STEP.

As foot movement, putting down the sole of the foot by ankle movement and then lift the sole of the foot, for instance operating a pedal, is all together one STEP.

BEND - B
The BEND activity is about bending the trunk so far that the hands reach below knee level and rise. The BEND activity begins and ends with the trunk in upright position and includes a bending of the trunk so the hands reach below knee level and the rising to an upright position. Sitting down on a chair and arise from the chair is one BEND activity. Kneeling on both knees and then arise are two BEND activities.

3.3.4 Repetitive activities

There are numerous of repetitive activities to include in the SAM system, however only one is relevant for this project; SCREW, hence the rest will be not included a theory. The SCREW activity is about rotating an object around its axis with hand or fingers or with a tool. The SCREW activity includes a complete sequence rotating the object around its axis and bring it back the hand or fingers or the tool so that the following SCREW activity can start.

3.4 Quality

Quality is a research area that is investigated and examined in several steps and with different engineering tools. The quality chapter starts with perceived quality and how that aspect is connected to the objectives of this project. The next section in the quality chapter is the engineering tool Process Failure Mode and Effect Analysis, henceforth referred to as PFMEA which is used to identify possible risks that can have a negative effect on the end product quality. The last part of the quality chapter is a Cause-and-Effect analysis, henceforth referred to as Ishikawa diagram.

3.4.1 Perceived quality

Perceived quality is a very important aspect to consider when designing cars for a global competitive market. It is not enough to reach the objective of zero defectives in today's highly competitive market (Stylidis et al., 2015). Greater advantages can be reached by understanding the customer's perception of quality. Car makers has to create the right "feeling" for the customer by influencing product features such as aesthetics, functionality and emotions. This feeling of quality is highly subjective and engineers tend to rely on previous experience and intuition in the design process.

The perceived quality varies greatly between different fastening options, especially on visible exterior parts. Thus, this is an important consideration when comparing fastening techniques for exterior plastic parts on car bodies (Stylidis et al., 2015).

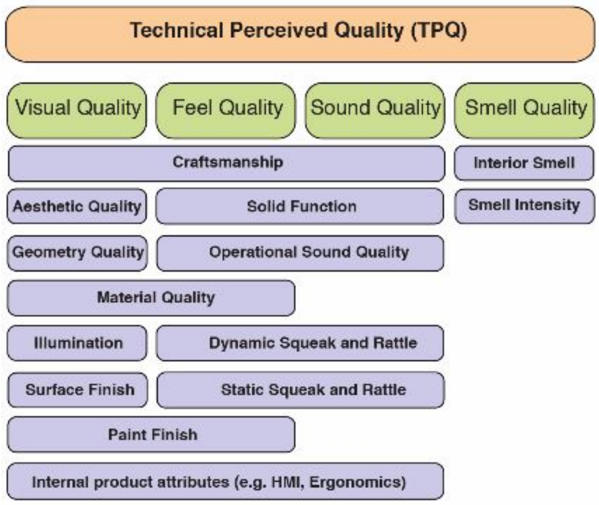

Figure 3.14: Illustration of the technical perceived quality by Stylidis et al. (2015) (Stylidis et al., 2015)

3.4.2 PFMEA

An assessment of possible risks and the severity of these risks will be made to deepen the analysis and comparison of the two fastening techniques (Arbetsmiljöverket, 2012). PFMEA - Process Failure Mode and Effect Analysis is a technique that evaluates potential failures, its effects, the severity and what kind of countermeasures that is available. The idea is to work in a preventive way, to identify and address a problem before it occurs. The severity grade works as a structured way of ranking different failures to prioritize the most important failures first. The process creates a risk awareness in early phases and enables proactive thinking. The prevention of possible failures is value adding since it saves money to prevent a costly problem from happening with a less costly countermeasure. It improves the analysis of this project by illustrating potential risks that depends on the fastening method (Arbetsmiljöverket, 2012).

Process: Defines the process steps and what actions performed by the operator that should be analysed.

Potential failure mode: Potential problems that can occur in the process as a result of the actions taken by the operator in the earlier defined process steps.

Potential effects of failure: Defines the possible effects of a failure occurring and as it appears to the customer and how it affects the system. The possible outcome of each assumed condition on the overall system. Each effect needs to be analyzed to assure customer and system satisfaction.

Severity (S): Assessment and ranking of the seriousness of the effect of the potential failure mode in the supply chain or to the customer. The ranking results when a potential failure mode results in a defect for the supply chain or the customer. The ranking is done with an assigned scale from 1 to 10 where a value of 1 remotes a severity that has no notable effect and a value of 10 remotes a very high severity warning where the human health and safety is in danger without warning.

Potential cause: Defines the potential root cause to why a failure occurs. Each failure can have several underlying causes.

Occurrence (O): This column is used to quantify the likelihood of occurrence of the actual potential failure mode. It is done with an assigned scale from 1 to 10 where a value of 1 remotes a failure that is unlikely to happen and a value of 10 remotes persistent failures.

Controls: This column provides a list of current process controls to either prevent the failure mode from occurring or detect it before it should occur. It is divided into prevention controls and detection controls.

Detection (D): This column defines the operator's ability to detect the potential failure and to accurately estimate the effects. It is ranked on a scale form 1 to 10 where 1 is very high chance of detection and 10 is almost impossible to detect.

Risk priority number (RPN): The multiplication of severity, occurrence and detection gives us a risk priority number, see equation 3.1. Higher numbers should be prioritized and further analysed. However, the severity number has a higher significant than the rest and should be considered foremost.

$$S \times O \times D = RPN \tag{3.1}$$

3.4.3 Ishikawa diagram

A process is subject to breakdown when certain events occur externally or internally which automatically leads to system failures. The purpose of an Ishikawa diagram (cause-and-effect diagram) is to derive possible events causing failures with deductive logic to understand the underlying causes (Kabir, 2017). By determining the system dependability, the connection between faults and causes can be identified. The results are used to strengthen the design and quality for future operations (Kabir, 2017).

An Ishikawa diagram is deductive since it goes from top to bottom. It starts with a main event, a system failure, and works downwards in the hierarchy to find the root causes of the system failure (Kabir, 2017).

3.5 Ergonomics

In today's manufacturing industry, it is in the best interests of most industries to build workplaces where the greatest possible diversity of people regardless of age and gender are able to to perform well, meaning that physical, cognitive and organizational sides of ergonomics are equally powerful aspects in the design of inclusive workplaces (Berlin and Adams, 2015). For car manufacturing, the high production pace puts high requirements on repetitiveness, job rotation and efficient workplace design. The purpose of production ergonomics is to design a workplace that will enable performing its operations without running the risk of injury, pain, discomfort, demotivation, and confusion (Berlin and Adams, 2015). A well performing workplace from an ergonomic point of view places demands on the product, process, operator and the organization.

Assuming a manual assembly, there are several workplace ergonomics evaluation methods available, such as RULA (Rapid Upper Limb Assessment), REBA (Rapid Entire Body Assessment) and KIM (Key Indicator Method) Lifting-Holding-Carrying

(Berlin and Adams, 2015). These are evaluation matrices that puts quantitative data on the ergonomic aspects of the workplace, which enables analyzing a current state against a future state. Nevertheless, this project is not about developing a new workplace design but to analyze existing methods of joining techniques. Besides physical ergonomic aspects, cognitive ergonomics is an important field to cover as well, since the methods might differ in this. For this project, KIM III, The Key Indicator Method for repetitive work, will be used to assess potential ergonomically risks (Arbetsmiljöverket, 2012).

This project will also pay attention to Volvo Car Corporation Ergonomic requirements which conforms to the Council of the European Communities (Karlsson, 2017). Volvo Car Corporation Ergonomic requirements which conforms to the Council of the European Communities states that a maximum pressure of 50 N is allowed when providing pressure with the whole hand and 30 N if only using fingers to provide pressure. Fasteners shall be placed so they are easily accessible during assembly. Fasteners and clips shall snap or give some kind of indication to the operator when correctly mounted (Karlsson, 2017).

According to the tape suppliers Tesa and 3M, no adhesive tape application requires more pressure than 30 N/cm^2 tape. For most acrylic foam tapes it is recommended to provide 20-30 N/cm^2 tape (Tesa, 2016b).

3.5.1 Cognitive ergonomics

Human workers are often preferred in assemblies over robots due to their ability to respond to variations in assembly instructions and quickly take decisions to address deviations from the normal process flow (Berlin and Adams, 2015). This is the case in many car assemblies, and also in this very case for CEVT in the process of joining exterior ca body parts. Humans are constantly learning, thinking and processing, which however can lead to misinterpretation or mistake making. Cognitive aspects of a workplace concern the sensory signals that give our brains the clues and cues to understand a task or to solve a problem. With some basic knowledge of good cognitive design principles, unnecessary mental workload, errors and misinterpretations can be minimized and help the operator perform their task more efficiently (Berlin and Adams, 2015).

The importance of proper working instructions to minimize the risk of quality defects in manufacturing should always be considered (Berlin and Adams, 2015). Appropriate lighting and working postures, screens showing the working sequence and exactly how the work is done, in addition to cognitive help as in "pick by light". These are all concepts that supports the assembly and the higher the complexity of an assembly, the higher the importance of proper aid (Berlin and Adams, 2015). There are some specific design principles supporting human cognitive capabilities of attention, perception, memory and mental models (Berlin and Adams, 2015), where

"Design for assembly/application" has been specifically derived to help supporting this project.

3.5.2 Design for assembly (DFA)

DFA, Design For Assembly, should be considered at all stages of the design process, but especially during the early phases (Boothroyd et al., 2001). DFA is specifically used to analyse a specific assembly process to make it easier to assemble with a higher productivity. The purpose is to facilitate the identification of assembly difficulties.

One part of DFA is to analyse the complexity of a product in terms of its unique number of parts. The complexity can also vary for identical products but with different fastening techniques. The complexity increases when the total number of parts increases. The number of unique parts to produce a car affects material handling costs and assembly costs directly. It is desirable to minimize the number of parts and standardize as much as possible to facilitate material handling and production (Samy and ElMaraghy, 2010).

The Integrated Design for Assembly Evaluation and Reasoning System (IDAERS) is a way of mapping assembly difficulties in a process. It is categorized into 6 groups: 3 levels (component, system and process) by 2 phases (acquisition and assembly). In this project it is possible to analyse the assembly phase specifically and not the acquisition phase since there are no bigger differences in the acquisition. In the assembly phase, Level 1 is Stability (difficulty represented by parts which require restraint or extra manipulation), level 2 is Clearance (difficulty that arises from the relative clearance between parts) and Direction (difficulties from having to move the part in various directions), level 3 is Fastening method (difficulty presented by the method used to fix the part for assembly) and Assembly path (difficulty associated with the path the component follow during the assembly process) (Tuve Skadecenter Workshop, 2017).

Boothroyd et al. (2001) states that an essential ingredient of the DFA method is the use of a measure of the DFA index of a design (Boothroyd et al., 2001). The two main factors that influence the the assembly cost of a product is the number of parts in a product and the ease of handling, insertion, and fastening of the parts (Boothroyd et al., 2001). The equation for calculating the DFA index E_{ma} is:

$$E_{ma} = N_{min} t_a / t_{ma} \tag{3.2}$$

Where N_{min} is the theoretical minimum number of parts, t_a is the basic assembly time for one part, and t_{ma} is the estimated time to complete the assembly of the product (Boothroyd et al., 2001).

This index will however not be applicable on this project, since the sub assembly of the actual part is not considered. The index will therefore be modified with the assembly time of the part to the car, instead of the sub assembly of the part.

3.6 Evaluation matrix

An evaluation matrix will serve as a way of organizing and quantify the technical parameters, research areas and the results of its corresponding engineering tools analyses to a set of defined criteria. All process selections involves trade-offs since there is no perfect process that fits every situation. The evaluation matrix works as a organizing tool to asses these trade-offs in a structured way (WFP Office Of Evaluation, 2017). The trade-offs are results of both external circumstances and internal process characteristics which is unique for every situation (Sturges and Kilani, 1992).

Knowledge of different fastening techniques is vital to stay competitive and continuously improve economical ratios for a manufacturing company in the automotive industry. Incorrect joining methods results in cost consuming waste activities and a loss of quality simultaneously. Technical evidence is needed to prove which joining method to use in a certain situation. Reality consists of far more complexity and uncertainty than what a theoretic model can grasp. But to enable information to take necessary decisions, reality needs to be simplified into a more understandable model. This model will work as an attempt to provide quantifiable data that more or less corresponds to reality (WFP Office Of Evaluation, 2017).

As a base for this matrix, the process selection model (LeBacq et al., 2001) will be used for evaluating and selecting appropriate fastening techniques for different scenarios. A thorough strength-weakness analysis of joining methods that allows for direct comparison to base future decisions on will be made. The framework will show the performance of a specific joining method on a set of parameters and compare it to another joining method more or less suitable for the situation. The purpose is to present quantifiable data that facilitates joining method selection decisions. This data is based on consultancy with experts, literature, own reflections and in-house expertise. The theory sections about tape and snap-fit fasteners serves as a database for the analysis.

All technical parameters with its corresponding theoretical base that is of importance for the analysis is presented in the section. The technical parameters are derived from the earlier described methodology where literature, quantitative and qualitative data are the three cornerstones (Berlin and Adams, 2015). With input from requirement specifications of the product groups, the adhesive tape and mechanical fasteners, the parameters are picked out (de Wit and Poulis, 2012; Ahlstrand, 2017; 3M, 2017). The parameters are sorted and refined to grasp the aim and scope of the project in a correct way through discussion with experienced engineers and among the project group. This section follows the product life-cycle as in engineering, production, final product and after market parameters. Every phase is connected to and affected by its own parameters and characteristics which is important to consider throughout the analysis. All together, this section will function as a theoretical base and framework for further analysis. The idea is to grasp and later on evaluate all important parameters that is affected by the choice of fastening technique.

The evaluation matrix considers four product flow phases presented below; Engineering, Production, Final product, and After market.

3.6.1 Engineering

Engineering parameters consists of all parameters that gets affected by the choice of attachment technique up until the production phase starts. The engineering phase includes all activities performed by Design, RD and Manufacturing Engineering at a car producing company. This phase is also affected by the supplier and material handling activities.

1. **Manufacturing engineering** - The manufacturing engineering department does some validation and preparatory work before the production can start. Manufacturing engineering usually works in close collaboration with R&D design to enable a smooth manufacturing for the car.

2. **Supplier manufacturing** - The supplier performs a manufacturing of the plastic part itself as well as a pre-assembly before shipping it to the OEM. Depending of the profile complexity and attachment part cost (adhesive tape or snap-fit fasteners), the final price for the OEM varies.

3. **Tolerance requirements** - Geometrical requirements for production to work properly. Tolerance requirements to assure a quality attachment. It is important to avoid built in tension due to tolerance distances resulting in shear loading and worse fastening. Surface geometry tolerance requirements involves both angles [degree] and roughness [μm] that can affect the adhesive tape performance.

4. **Design freedom** - The freedom of being able to design according to needs at the R&D design department. Less design constraints mean a freer design option with fewer constrictions.

5. **Design flexibility** - The ability and possibility to make late changes in development of the car. Today's demand in technology and innovation is constantly evolving, and being able to make changes through the development process can be vital.

6. **Design complexity** - The number of parts determines the design complexity, Design For Assembly (DFA). Engineering and asembly time can be derived from this factor.

7. **Material flow** - The material flow considers all material handling, transportation and storing. The size and quantity of the part decides how the material flow looks like.

3.6.2 Production

A set of criteria for the production phase that is affected by the choice of attachment technique has been identified. The production phase is closely connected to the actual application of a certain attachment technique. The performance of application affects the final product and customer satisfaction in terms of quality and cost.

1. **Repeatability** - The repeatability of the process considers the trustworthiness and robustness of the process. The ability of an operator to consistently repeat the same measurement of the same part using the same gage, under the same conditions.

2. **Assembly time** - The total amount of time required to perform a complete assembly. This will be a combination of a qualified estimation made by experts and the time study using MTM-SAM.

3. **Quality assurance** - The possibility to detect defects in the production process after the assembly is done. Depending on the fastening method, there are different levels of "hidden" possibilities of quality drawbacks.

4. **Operator dependability** - How dependent the quality is of the operator's skills in production. This is equivalent to reproducibility where low reproducibility is equal to high operator dependence.

5. **Process supervision** - The level of control needed to supervise the process to maintain the desired quality. Connected to investments in equipment and other supervisions tools needed.

6. **Preparation of joint** - Prerequisites regarding hole and surface requirements needed to create a robust basis for the attachment process. This included surface treatment as in cleaning and adjustments from the stamping process.

7. **Environmental dependability** - The dependability of environmental factors that can be affected by humans, such as cleanliness and dry surfaces. Also external environmental factors that cannot be affected by humans, such as temperature and humidity.

8. **Ease of repair/adjust** - If a quality problem occurs in production, the ease of repair considers the ability to adjust the fault while the production is still up and running.

9. **Cognitive ergonomics** - The level of cognitive support provided for the fastening methods.

10. **Equipment** - The amount of equipment needed to compensate the cognitive support, such as fixtures. But also equipment such as tools to provide support for the need of maintenance.

11. **Consumables** - The consumables needed to support the requirements of the process, such as wipers to maintain clean and dry surfaces.

12. **Health and safety** - Health and safety risks that comes with the process. For instance chemical substances or physically dangerous equipment.

13. **Physical ergonomics** - Physical ergonomic risks that is affected by the choice of fastening technique.

3.6.3 Final product

Final product parameters consists of all parameters connected to the performance and characteristics of the final product, the plastic extension mounted on the car body and how it affects the customer satisfaction of the total car.

1. **Strength of bond/peeling resistance** - The pull-off force or the defined holding force is the force required to remove an adhesive tape from a specific surface with a predefined speed.

2. **Temperature resistance** - The coefficient of thermal expansion differs between different materials and tells how much a change in temperature causes a geometrical expansion.

3. **Perceived quality** - The perceived quality of the detail includes five different aspects that should be considered, feel, sound, visual, and smell.

4. **Cold shock absorption** - Cold shock absorption tells how well a specific adhesive can absorb high shock loads during cold temperatures.

5. **Noice vibration harness** - Vibration occur due to motion and affects the attachment throughout its life-cycle. Shear loading is a constant force applied to the detail and its fastening due to gravity.

6. **Strength to weight ratio** - What is the strength ratio of the fastening technique when divided by the required weight for the part and its fasteners. A higher strength to weight ratio enables a lighter part and a lighter car with the same fastening strength.

7. **Corrosion resistance** - How is the corrision resistance affected by the choice of fastening technique.

8. **Solvent resistance** - Weather resistance involves all types of effects that occurs because of weather. Temperature, humidity, wind are weather factors that affects the detail and the chosen fastening method constantly.

9. **Sealing function** - Do the fastening technique provide a sealing function to keep out dirt and moisture from the inner layer of the part.

3.6.4 After market

During the after market the car has a need of service which includes disassemble and reassemble activities. The automaker has to provide design solutions that support these kind of activities. Serviceability can be defined as the easiness of replacing damaged parts of the car. Maintenance is defined as a combination of all technical, administrative and managerial actions during the life cycle of an item and, intended to retain it in, or restore it to, a state in which it can perform the required function. Serviceability is the measure of a set of features that supports the ease and speed of performing maintenance on a system (WFP Office Of Evaluation, 2017). Service can either be corrective or preventive. Corrective maintenance includes all actions taken to repair a failed system and can be quantified with the measure Mean Time to Repair (MTTR). Preventive maintenance is to perform preventive countermeasures before failure occur and can be quantified with the measure Mean Preventive Maintenance Time (MPMT). The following list of criteria includes all after market activities that is affected by the choice of attachment technique.

1. **Quality of reattached joint** - How good the durability and reliability of a reattached joint is.

2. **Ease of removal** - What grade of complexity and time needed when removing the plastic extension from the car body. If tools or solvents are needed to remove, this is also considered here.

3. **Ease of reattaching** - How easy and fast a mechanics can reattach the plastic extension. If tools or solvents are need to reattached, this is also considered here.

4. **Possibility to reuse part** - The possibility to reuse the plastic extension

with minimum scrap.

5. **Possibility to recycle part** - The possibility to recycle the plastic extension and to what grade.

6. **Do it yourself** - The possibility to perform reparations or adjustments by yourself as a customer.

7. **Merchandise** - Availability of spare-parts and accessories.

4

Analysis

The analysis chapter is built upon the implementations and results of the project. It starts with process maps of adhesive taping and mechanical fasteners to clearly describe joining processes as in what is done in what step and in what sequence. Further on, a competitor analysis lays the ground for how different fastening techniques are used today by competitors and to identify possible improvements. Following the competitor analysis is a cost model that is made to act as a framework for future cost calculations and estimations when selecting between different joining techniques in car manufacturing. A time study is done with MTM-SAM on a representative case to clarify the time consumption of both fastening techniques. The quality chapter that follows consists of PFMEA, Ishikawa diagram, design principles and perceived quality to highlight certain do's and don'ts with respect to the end product quality. Finally, the evaluation matrix acts a as a final delivery to provide insights in the strengths and weaknesses of both attachment techniques.

4.1 Mapping of processes

The processes including all required steps in production assembly are defined and mapped in this section for both joining methods. First a function analysis presents the functions of the processes which is followed by a process map including explanations for every step in each joining technique.

4.1.1 Function analysis

To broaden the understanding and map the characteristics of adhesive taping and mechanical attachment of car body parts, a function analysis was developed. The functions of the processes are presented in Figure 4.1, where process 1 and process 2 concerns mechanical attachment and adhesive taping respectively.

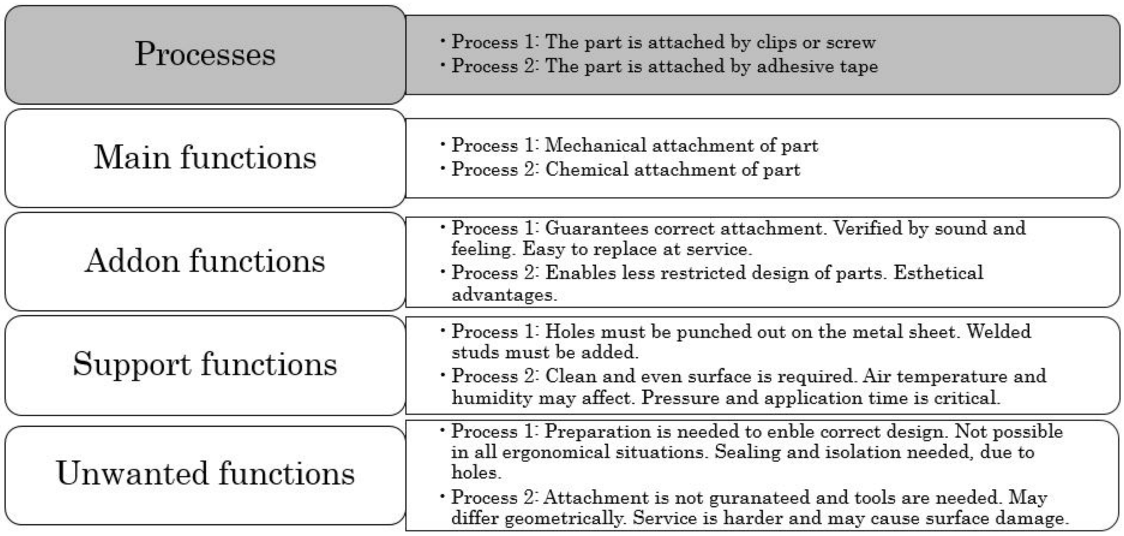

Figure 4.1: Function analysis

4.1.2 Snap-fit process

The snap-fit fastening processes are presented in Figure 4.2. The production processes for snap-fit fasteners consists of; hole generation, positioning and pressing.

Figure 4.2: Snap-fit process

Hole generation - Hole generation is done directly to the car body, before the assembly line. The hole generation process consists of four main process steps, drawing, bending, cutting and stamping.

Positioning - The positioning is done at the assembly by steering the snap-fits towards the holes (poka yoke). The positioning can be done with guide pins, fixtures or just by manual positioning.

Pressing - The part is later pressed to the body with a certain force until a snap sound occurs.

4.1.3 Adhesive tape process

The production processes for adhesive tapes consists of; clean surface, dry surface, positioning, liner removal, and pressing, as shown in Figure 4.3.

Figure 4.3: Adhesive tape process

Clean surface - The assembly starts with cleaning the surface, to remove all dirt and oil spill.

Dry surface - When the cleaning is done it is important to assure that the surface is dry and has the right temperature.

Positioning - The positioning must be done with guide pins or a fixture to ensure the correct position of the part. This is a critical step when joining with adhesive tape and is the most significant difference from snap-fit fasteners.

Liner removal - When the part is in position, the liner is removed and the part pressed on to the body.

Pressing - The pressing has to be done with a certain force during a certain time span to ensure wetting.

4.1.4 Hybrid process

The hybrid process is a combination of snap-fit and adhesive fastening, thus it consists of; hole generation, clean surface, dry surface, positioning, liner removal, and pressing. Note that the liner removal can be performed before positioning in some cases. The hybrid process is presented in Figure 4.4.

Figure 4.4: Hybrid process

4.2 Competitor analysis

A technical competitor analysis has been performed to identify the techniques used by other car manufacturers by assessing the website A2MAC1 (2017) reversed engineering. The idea is to map the techniques to enable a thorough analysis of pros and cons and to create recommendations based on this learning. By benchmarking Lynk Co's attachment solutions to best in practice it is possible to come up with significant improvements for future cars.

A broad set of 15 mass produced car models from a variety of original equipment manufacturers is selected to increase validity and to ensure that no details gets overlooked. Each car's technical attachment solution for fender flares, lower door side protection molders and rocker panels (plastic runners) is described in the following list. The car models ranges in price from a budget car to a luxury car with a corresponding model year of no older than 2012 up until today. Maximum one model from each car manufacturer is examined and the car manufacturers are chosen in a way to increase diversity, thus avoiding several cars from the same original equipment manufacturer and geographical proximity. Following from A2MAC1 (2017), the following set of cars have been examined:

- **Volvo XC90 D5 Inscription 2015**: The Volvo XC90 fender flare is attached solely with two different variants of clips. The rocker panels are designed with a carrier and an outer layer, the carrier is attached with one type of clips and one type of screw. The lower door side protection molding is attached with one type of clips.

- **Volkswagen Tiguan 2.0 TDi 4Motion Highline 2016**: The fender flare is attached with three types of clips. The side protection molding is attached with three types of clips. No side plastic runners/rocker panels exists.

- **Seat Ateca 2.0 TDi 4Drive Xcellence 2016**: The front fender flare is attached with tape over the chassis and a few screws at the bottom. The side plastic runner are attached with a large amount of clips of the same type and no screws. The side plastic runner is also running over half of the rear fender flare in one piece. The lower door side protection molding is attached with two types of clips and one type of adhesive tape at the bottom.

- **Hyundai Tucson 1.7 CRDi DCT**: The fender flare is attach with one type of clips and one small strip of adhesive tape on the upper corner. The lower door side protection molding is fastened with two types of clips in the middle and two adhesive tape strips, one on each corner. The rocker panel is fastened with two types of clips.

- **Honda HR-V 1.5 i-VTEC Executive 2015**: The rocker panel is fastened with two types of clips. The fender flare is fastened with two tupes of clips. No lower door side protection molding exists.

- **Ford Kuga 2.0 TDCi Titanium 2013**: The fender flare is attached with three different types of clips on both the outer side of the chassis as well as the inner wheel house. The rocker panel is attached with two types of clips. The lower door side protection molding is attached solely with clips.

- **Citroen C4 Cactus 1.2 PureTech ETG Shine Edition 2014**: The large middle door side protection molding is fastened with two types of clips and on small strip of adhesive tape in the upper right corner. The fender flare is attached with two types of clips. The rocker panel is attached with clips.

- **BMW X1 sDrive 18d 2016**: The rocker panel is attached with four different types of clips. The fender flares are attached with two different types of clips and one type of screw. The lower door side protection molding is attached with two types of clips.

- **Renault Kadjar 1.2 TCE Intense 2016**: The lower door side protection molding is attached with two different types of clips and one long stripe of adhesive tape on the upper edge. The fender flare is attached with three different types of clips and one type of screw. There exist no rocker panel/plastic runner.

- **Nissan Qashqai dCi All-mode Connect Edition 2014**: The fender flares are attached with two types of clips and one type of screw. The lower door side protection molding is fastened with one type of clip and one strip of adhesive tape on the right edge. No rocker panel/side runner exists.

- **Mazda CX-3 1.5 SkyActiv-D Dynamique 2016**: The fender flares are attached with four types of clips on both the outer chassis and the inner wheelhouse. The lower door side protection molding is attached with two types of clips. The rocker panel is attached with one type of clips.

- **Land Rover Range Rover Evoque 2.2 SD4 Prestige 2014**: The rocker panel is attached with one type of clips. The fender extension is attached with one type of clips. The lower door side protection molding is attached with one type of clips.

- **Audi Q3 2.0 TFSi Base 2012**: The lower door side protection molding is attached with one type of clips. No information of the rocker panel can be found. The fender flares are attached with two types of clips.

- **Fiat 500 X 2.0 Multijet Cross 2014**: The fender flares are attached with four types of clips, one type of screw and one type of adhesive tape. No lower door side protection molding exists. The rocker panel/side plastic runners are attached with two types of clips.

- **Kia Sportage 2.0 CRDi BVA AWD Premium 2016**: The rocker panel is attached with two types of clips. The fender flares are attached with one type of clips. No lower door side protection modling exists.

Distribution	Adhesive tape	Snap-fit fasteners	Hybrid
Fender flare	0/15	13/15	2/15
Door edge molder	0/15	10/15	5/15
Rocker panel	0/15	15/15	0/15

The distribution of today's design solutions clearly shows that a strong majority of cars uses snap-fit fasteners for fender flares, door edge molders and rocker panels. There is a small trend of hybrid solutions for door edge molders following a result of 5/15 using a hybrid solution, an even smaller trend can be seen for fender flares where 2/15 uses a hybrid solution. No original equipment manufacturer uses solely adhesive tape for these car body exterior plastic parts. A selection of examples for each part follows in the coming section to exemplify today's technological attachment solutions A2MAC1 (2017).

4.2.1 Fender flare

The fender flare is the plastic extension or exterior body part that varies the most between different car models when it comes to attachment techniques and design. Thus, it is the part that is most difficult to standardize and often gets overlooked by other interests. The technical competitor analysis shows us that the fender flare is most commonly joined with solely mechanical fasteners A2MAC1 (2017). In these cases, at least two different fasteners are often used, such as snap-fit and screw fasteners. In rare cases, up to five different fasteners can be used as in the case of Fiat A2MAC1 (2017). The fender flare design can be with or without a backing part, where Volvo uses a far more complex design with a backing part compared to the others that only has one layer of plastic with included clips-houses. There are mainly three different alternative techniques widely used for attaching the fender flare:

Alternative 1 - Adhesive tape: Alternative 1 is a fender flare that is completely fastened with adhesive tape. An example is Seat Ateca (2016) which uses adhesive tape for both the rear and front fender flare. This method require some kind of fixture to ensure that the fender flare is correctly positioned. The fender flare is divided in two halves to improve serviceability.

Figure 4.5: Seat Ateca Fender Flare

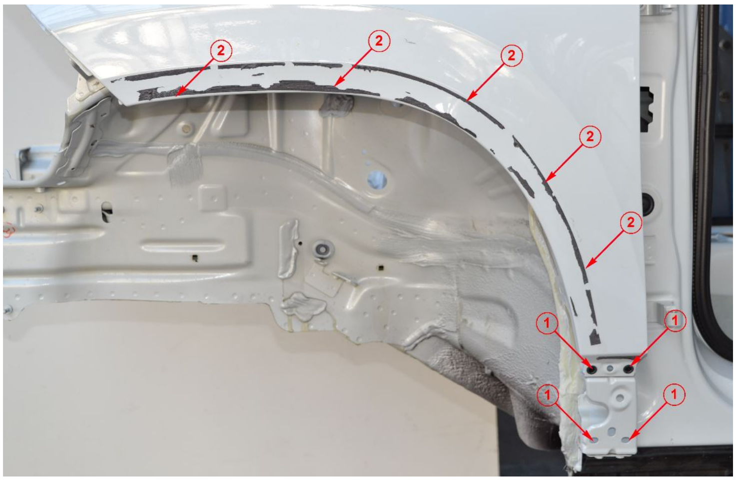

Figure 4.6: Seat Ateca Fender Flare adhesive tape fastening

Alternative 2 - Snap-fit fasteners: Alternative 2 is to attach the fender flare solely with snap-fit fasteners. Volvo XC90 and Volkswagen Tiguan uses this kind of technique. It provides a quality assured technique in the assembly but requires hole generation and stamping processes earlier in the process.

Figure 4.7: VW Tiguan Fender Flare snap-fit fastening

Figure 4.8: VW Tiguan Fender Flare

Alternative 3 - Hybrid: Alternative 3 is a hybrid, compared to a joining with solely mechanical fasteners or adhesive tape, it is attached with both techniques simultaneously. As shown in Figure 4.9, the fender flare is attached with snap-fit fasteners and supported with a tape, making it a hybrid joining technique. The tape is located in the upper right corner in the figure. The fender flare visualized in Figure 4.9 is from a Hyundai Tucson 2016 A2MAC1 (2017).

Figure 4.9: Fender flare with hybrid bonding. Hyundai Tucson 2016 A2MAC1 (2017)

4.2.2 Door edge molding

After thorough investigation at a2mac1.com, it has been seen that the door edge molding is most commonly fastened solely with mechanical fasteners A2MAC1 (2017). If the part is joined with solely mechanical fasteners, a sealing is sometimes added to prevent dirt and water to enter the gap on the upper edge. The design shown in Figure 4.10, is a hybrid joint from an Audi Q3 2013. In this case, the hybrid joint consists mainly of adhesive tape and is supported by four snap-fit fasteners. Due to the high amount of tape, there is no need to add an extra sealing.

Figure 4.10: Door edge molding with hybrid bonding, clips and adheisve tape. Audi Q3 2013 A2MAC1 (2017)

Alternative 1 - Snap-fit fasteners: The first alternative shows a fully snap-fit fastened door edge modler from BMW X1.

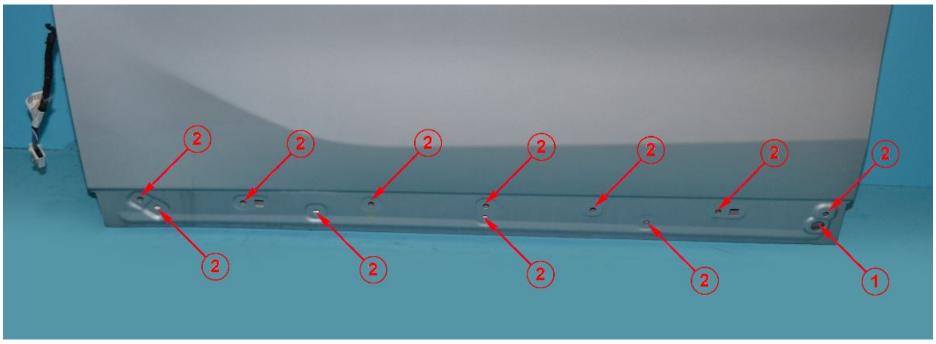

Figure 4.11: BMW X1 Door edge molder with a snap-fit fastened fastening technique

Alternative 2 - Hybrid: Honda, Hyundai and Audi uses the similar technology for fastening the door edge molding. A hybrid technology consisting of both snap-fit fasteners and adhesive tape according to the following picture.

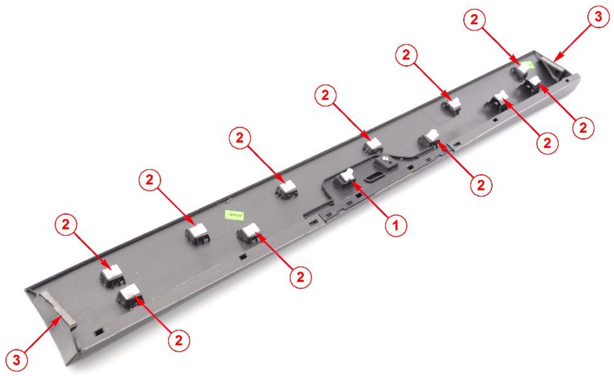

Figure 4.12: Honda HR-V Door edge molder with a hybrid fastening

4.2.3 Rocker panel

The rocker panel can consist of two parts, an inner carrier and an outer shell. The inner carrier is often fastened more robustly with screws and bolts while the outer shell is fastened with snap-fit fasteners according to the following BMW X5 pictures. A rocker panel can also consist of one part like in the case of Citroen C4 Cactus **??**. According to most car models from a2mac1.com, the rocker panel is usually attached with mechanical fasteners as well A2MAC1 (2017). The rocker panel commonly comes with sealing to keep the inside area sealed and dry. The rocker panel shown in Figure 4.13, a Volvo XC90 2016, is joined with two different snap-fit fasteners.

Figure 4.13: Rocker panel with mechanical bonding. Volvo XC90 2016

Alternative 1 - Snap-fit fasteners: Snap-fit fasteners is the only common technique for attaching rocker panels. Sometimes with more than one type of snap-fit fastener.

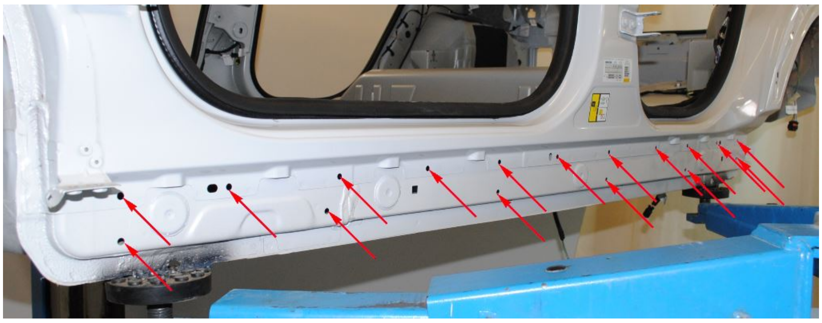

Figure 4.14: Citroen C4 Cactus Rocker panel with snap-fit fasteners.

Alternative 2 - Screw and bolt: BMW X5 is a car with a rocker panel that consists of one inner carrier and one outer shell. The inner carrier is attached with screw and bolt while the outer shell is fastened with snap-fit fasteners.

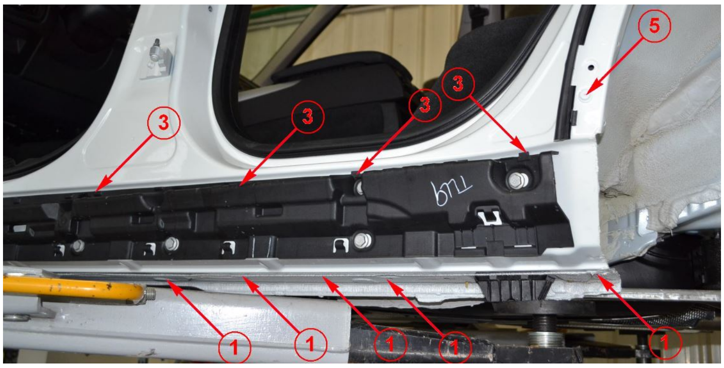

Figure 4.15: BMW X5 Rocker panel carrier

Figure 4.16: BMW X5 Rocker panel shell

4.3 Economy

The cost calculation is important for the project results and recommendations on fastening processes by highlighting relative differences between both attachment methods with respect to costs. This being a comparison between adhesive tape and clips means that factors not dependent on the attachment technique will not be taken into consideration. Also, some cost factors that are not substantial for the total cost and cannot be estimated due to lack of data or resources will be assumed. These calculations assumes well functioning and stable processes with requirement and quality fulfillment on all levels. Fixed costs such as the need of new machines and equipment will be roughly estimated. Running costs as in direct material costs and direct labor costs will be estimated with the help from CEVT employees. It is important to point out that this is a cost estimation of a fictive case with an up and running production process with perfect supply. Logistics, stock and material handling will not be considered since it is approximately the same for both methods regardless of which one to use.

The proposed cost model below is a merge between the (Freivalds and Niebel, 2009) model and (Dhillon, 2012) definitions described in the theory chapter. Both theories are developed further to fit the situation of two different fastening techniques in car manufacturing and its corresponding cost factors. Critical cost factors affected by the choice of fastening technique are sorted out and chosen to be included in a newly developed model heavily influenced by (Freivalds and Niebel, 2009) and (Dhillon, 2012) which is illustrated in Figure 4.17.

Investment		
Engineering, Factory & Equipment, Tooling, Area		
Direct costs		
Direct material costs (DMC = DM1 + DM2 + DM3)	DM1 Subcomponents DM2 Subcontracted parts DM3 Standard items	Clips/Tape Plastic extenstion Consumables
Direct labor costs (DLC = DL1)	DL1 Operator hours	Wage
Overhead costs		
Material overhead % (MO = Markup percentage of the direct material costs)	Material handling Warehousing	
Production overhead % (PO = Markup percentage of the direct labor costs)	Energy Maintenance	
SG&A overhead % (SGA = Markup percentage of the total material & production costs)	General sales Administration	
Total cost = (DMC + DLC + (MO*DMC) + (PO*DLC)) * (1 + SGA)		
MSRP = Total cost + scrap amount + profit		

Figure 4.17: Cost factors

The cost factors are calculated as seen in Figure 4.18 and are based on a case where four wheel fender flare extensions are assembled to a car in a Chinese factory by Chinese workers. Assumptions has been made together with CEVT finance department as follows: Overhead costs are calculated with the following percentages, Material Overhead 20 %, Production Overhead 20 , SGA Overhead 10 . A forecast of 8 years, 12 % Weighted Average Cost of Capital (WACC) and a yearly volume of 150 000 cars are assumed. Direct Material costs are based on assumptions made together with experienced suppliers of plastic extensions. Direct Labor costs are based on Chinese wages which corresponds to 10,14 SEK per minute and the assembly times are based on the MTM-SAM calculations which corresponds to 44 seconds for adhesive taping and 29 seconds for snap-fit fastening assembly. The quality revenue are based on the quality characteristics of the final product. The after market revenue are based on observations during field trips to workshops where it is clear that the service on a adhesive taped extension is more expensive when compared to a snap-fit fastened extension.

By observing 4.19, it is seen that adhesive tape has higher investment costs and therefore a negative cash flow the first two years when compared to clips which only has a negative cash flow the first year. Although, adhesive tape reaches a somewhat higher cash flow from the third year and onwards where clips still has a positive cash flow but not exactly as high. This is because of the assumption that adhesive tape being able to generate a more attractive design and a small edge in quality when being compared to the clips solution. Clips has a positive edge when it comes to the after market revenue but it is not enough to triumph over adhesive tape's quality revenue.

When looking at the 4.20, it is clear that clips has a higher accumulated cash flow compared to adhesive tape although both techniques shows positive figures when the pay back time is due. The pay back time for clips is 1,1 years and the pay back time for adhesive tape is 2,1 years. Both graphs converges over time and one can argue that adhesive tape has an edge when being calculated with longer time horizons and higher volumes.

General		Labor cost		Overhead costs		Profitabilty Metrics Adheisve tape		Profitabilty Metrics Clips	
Forecast	8 years	RMB/min	7,8	Material overhead	20%	**NPV**	**20 174 612**	**NPV**	**31 770 198**
WACC	12%	SEK/min	10,14	Production overhea	20%	**IRR**	**56%**	**IRR**	**109%**
Volume	150 000	Assembly time tape	44	SG&A overhead	10%	**Pay back Period**	**2,1**	**Pay back Period**	**1,1**
Currency	SEK	Assembly time clips	29			**Time to Break Even**	**1,9**	**Time to Break Even**	**1,1**

Cash flow Adheisve tape		**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Total investment (-)	-6 000 000	-3 000 000	-3 000 000	0	0	0	0	0	0	0
Payback (+)		0	19	19	19	19	19	19	19	19
Direct material cost (-)		0	-100	-100	-100	-100	-100	-100	-100	-100
Direct labor cost (-)		0	-30	-30	-30	-30	-30	-30	-30	-30
Material overhead % (-)		0	-20	-20	-20	-20	-20	-20	-20	-20
Production overhead % (-)		0	-6	-6	-6	-6	-6	-6	-6	-6
SG&A overhead % (-)		0	-16	-16	-16	-16	-16	-16	-16	-16
Quality revenue (+)		0	12	12	12	12	12	12	12	12
After market revenue (+)		0	7	7	7	7	7	7	7	7
MSRP (+)		0	171	171	171	171	171	171	171	171
Volume effect (Quantity)	22 800 000	0	2 850 000	2 850 000	2 850 000	2 850 000	2 850 000	2 850 000	2 850 000	2 850 000
Total Cash Flow	16 800 000	-3 000 000	-150 000	2 850 000	2 850 000	2 850 000	2 850 000	2 850 000	2 850 000	2 850 000
Accumulated Cash Flow	51 600 000	-3 000 000	-3 150 000	-300 000	2 550 000	5 400 000	8 250 000	11 100 000	13 950 000	16 800 000
Cash flow Clips		**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Total investment (-)	-3 000 000	-2 000 000	-1 000 000	0	0	0	0	0	0	0
Payback (+)		0	18	18	18	18	18	18	18	18
Direct material cost (-)		0	-100	-100	-100	-100	-100	-100	-100	-100
Direct labor cost (-)		0	-20	-20	-20	-20	-20	-20	-20	-20
Material overhead (-)		0	-20	-20	-20	-20	-20	-20	-20	-20
Production overhead (-)		0	-4	-4	-4	-4	-4	-4	-4	-4
SG&A overhead (-)		0	-14	-14	-14	-14	-14	-14	-14	-14
Quality revenue (+)		0	10	10	10	10	10	10	10	10
After market revenue (+)		0	8	8	8	8	8	8	8	8
MSRP (+)		0	158	158	158	158	158	158	158	158
Volume effect (Quantity)	21 600 000	0	2 700 000	2 700 000	2 700 000	2 700 000	2 700 000	2 700 000	2 700 000	2 700 000
Total Cash Flow	18 600 000	-2 000 000	1 700 000	2 700 000	2 700 000	2 700 000	2 700 000	2 700 000	2 700 000	2 700 000
Accumulated Cash Flow	71 200 000	-2 000 000	-300 000	2 400 000	5 100 000	7 800 000	10 500 000	13 200 000	15 900 000	18 600 000

Figure 4.18: Cost model

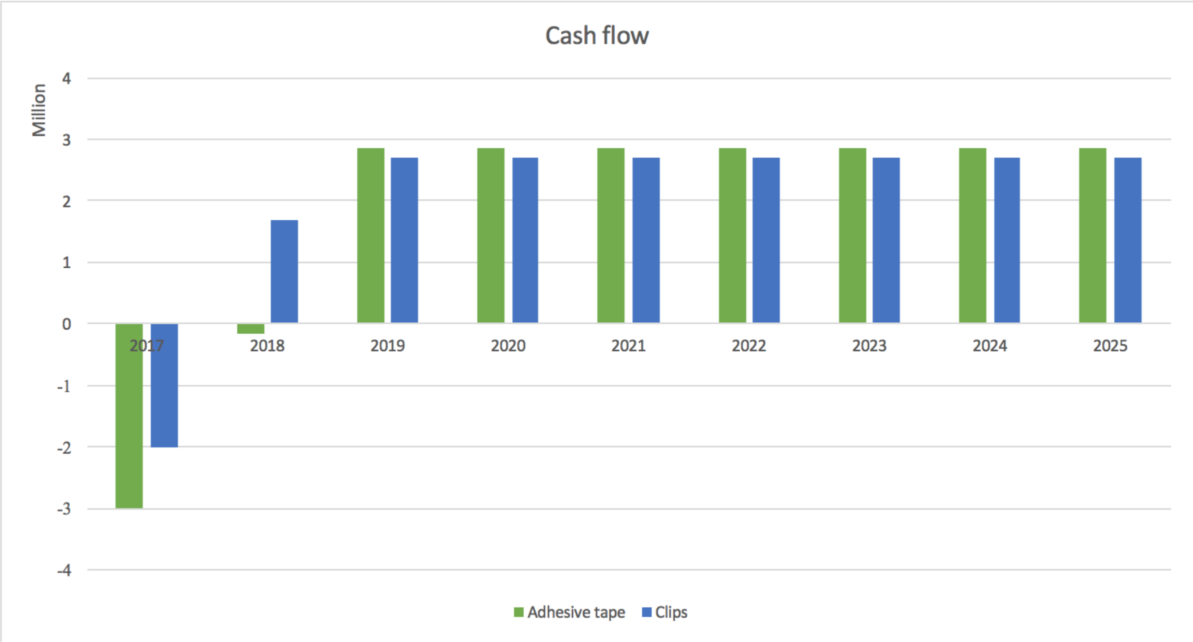

Figure 4.19: Cash flow

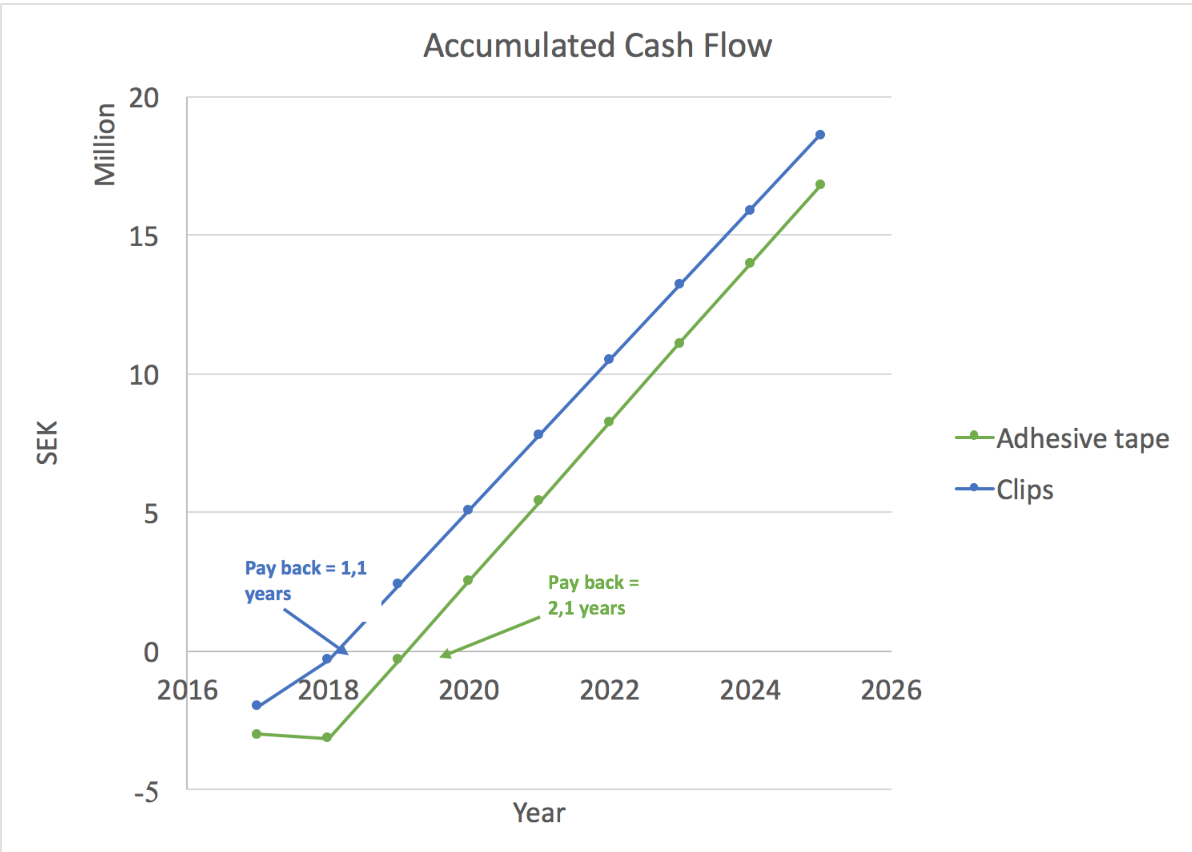

Figure 4.20: Accumulated cash flow

4.4 Time

To asses the time for a specific case, a time study with the aid of an MTM-SAM analysis of a fender flare is presented. The following section explains the results from the MTM-SAM analysis. The MTM-SAM analysis form is presented in Appendix C and the result from the study is presented in Table 4.1.

	Adhesive tape	Snap-fit fasteners	Hybrid
Total net time [factors]	245	161	310
Total net time [TMU]	1225	805	1550
Total net time [sec]	**44.1**	**29.7**	**53.1**

Table 4.1: The result from the MTM-SAM study

With approximately 34% faster assembly time compared to adhesive taping, the snap-fit fasteners is the fastest of all attachment methods, as shown in Figure 4.21.

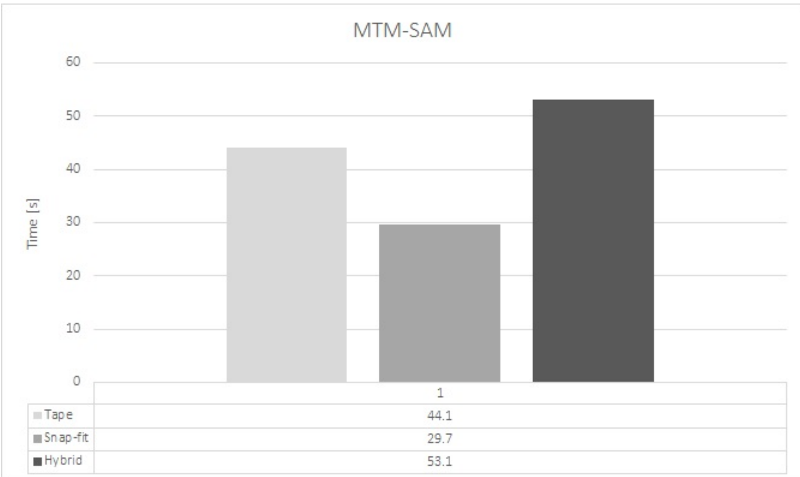

Figure 4.21: MTM-SAM bar chart

Value adding and non-value adding time has been calculated and compared between the different methods and is presented in the figures below. As seen, snap-fit fasteners has the most value adding portion of its total assembly time, all 73%. Hybrid and tape are only contributing with 60% respectively 54% value adding time to the total assembly.

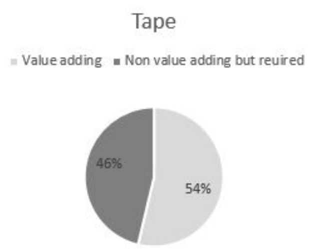

Figure 4.22: Tape

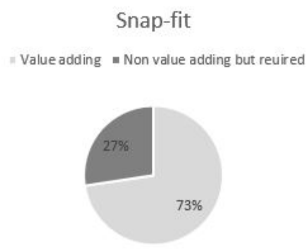

Figure 4.23: Snap-fit

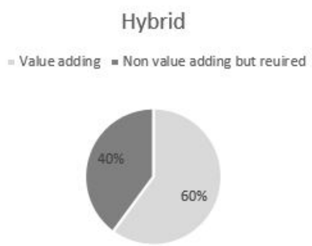

Figure 4.24: Hybrid

4.5 Quality

Quality is one of the research areas and the analysis that follows will be presented in this section. A set of engineering tools have been used to assess how the quality is affected by the choice of a fastening method. To do this, PFMEA is used to identify risks that can have a negative affect on the quality. Additionally, an Ishikawa diagram works as a way to sort out and illustrate possible causes for quality issues related to the fastening method.

4.5.1 PFMEA

Process Failure Mode Effect Analysis is a methodology that assesses possible risks and the severity level that follows. It enables the producer to implement countermeasures before they occur (Arbetsmiljöverket, 2012). The concerned processes analysed in the PFMEA is following the process steps described in the process mapping chapter for attachment techniques. The part that will be analysed is the fender flare but other product groups can be approximated with the base knowledge of risks gotten from the fender flare variant. Since no actual data or real case exists, a workshop is carried out to assess severity, occurrence and detection probabilities based on experiences from before. The workshop is performed in a team of 5-6 persons with high experience from car manufacturing. Team discussions which is based on earlier experiences and knowledge lead to the estimations presented in this section.

In total, two separate PFMEA are made, one for a fender flare attached with adhesive tape and one for a fender flare attached with clips according to the process descriptions described in the process mapping section. It is possible to draw similar conclusions of a hybrid variant, hence it will not be included.

When analysing the PFMEA made for the adhesive tape process there are four areas with the highest RPN value, as can be seen in Figure 4.25. Take, apply, and wipe off solvent to achieve a clean surface, and apply the right pressure for best wetting possible are the most likely failure modes to occur. The reasons for the high RPN values is because of the difficulty to see if the failure occurs or not, the process steps are very hard to control and requires supervision to assure quality.

When observing the clips PFMEA it can be noticed that the process with the highest RPN is applying pressure activity and the process with the second highest RPN is the positioning activity, as shown in Figure 4.26. When comparing to adhesive tape, the applying pressure activity scores a RPN of 175 instead of 225 as in the case of adhesive tape. The high RPN is because of its difficulty to detect and control the correct pressure, but still lower than adhesive tape because it provides a certain sound and feeling when the clip attaches correctly. The positioning has a higher severity because it directly affects the visuals of the car in addition to worsening the wet-out.

To summarize the risks analysis, one can argue that the risks that require further analysis and improvements for both attachment techniques are the applying pressure activity and to assure the right positioning. By comparing adhesive tape to the clips solution it is fairly similar when it comes to applying pressure and position, but adhesive tape is also heavily affected by the high risks of not attaining the correct surface conditions.

Issuer (dept, name, phone, sign.)	Date	Function	Process layout-Issue
FL, Filip Larsson, AT, Anton Tennby		ME	Fender flare adhesive tape assembly WITH FIXTURE
Change Order	**Part No**	**Part Name**	
		Fender flare	

No	Type	Variant	Process, part component-number	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause	Occur	Class	Current Process Controls - Prevention	Current Process Controls - Detection	Detec	RPN
1			Take wiper and add x ml of Isopropanol/primar	Too less/much Isopropanol/prima	Degraded wetting	5	Operator mistake/incorrect process	5	SC	Visual check	Visual check/Wetting test	9	225
2			Apply on surface until dissolved and clean	Not cleaned enough	Degraded wetting	5	Operator mistake/incorrect process	5	SC	Visual check	Visual check/Wetting test	9	225
3			Wipe off surface with dry wiper until dry	Not dried enough	Degraded wetting	5	Operator mistake/incorrect process	5	SC	Visual check	Visual check/Wetting test	9	225
4			Control surface and tape temperature	Wrong temperature	Degraded wetting	6	Incorrect process	5	SC	Measurement	Measurement	3	90
5			Place WAE in fixture	Wrong position	Degraded wetting, degraded aesthetics	7	Operator mistake/incorrect process/incorrect design	5	SC	Visual check/Fixture	Visual check/Wetting test	5	175
				Wrong variant	Wrong variant, wrong color	7	Operator mistake/incorrect process	5	SC	JIS Supply	Visual check	2	70
6			Postition fixture to car	Wrong position	Degraded wetting, degraded aesthetics	7	Operator mistake/incorrect process/incorrect design	5	SC	Visual check/Fixture	Visual check/Wetting test	5	175
				Wrong variant	Wrong variant, wrong color	7	Operator mistake/incorrect process	5	SC	JIS Supply	Visual check	2	70
7			Grab finger lift and remove liner	Not completely removed liner	Degraded wetting, no wetting	4	Operator mistake/incorrect process	5	SC	Visual check	Visual check/Wetting test	2	40
8			Apply pressure x Pa for y seconds	Not enough pressure for enough time	Degraded wetting	5	Operator mistake/incorrect process	5	SC	Poka yoke fixture	Visual check/Wetting test	9	225
9			Remove fixture	Removed incorrectly	Degraded aesthetics	7	Operator mistake/incorrect process	5	SC	Poka yoke fixture	Visual check	5	175

Figure 4.25: PFMEA Adhesive tape

Issuer (dept, name, phone, sign.)					Date	Function		Process layout-Issue					
FL, Filip Larsson, AT, Anton Tennby						ME		Fender flare adhesive tape assembly WITH FIXTURE					
Change Order				Part No		Part Name							
						Fender flare							
No	Type	Variant	Process, part component-number	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause	Occur	Class	Current Process Controls - Prevention	Current Process Controls - Detection	Detec	RPN
1			Pick up WAE	Wrong variant	Wrong variant, wrong color	7	Operator mistake/incorrect process	5	SC	JIS Supply	Visual check	2	70
2			Postition WAE to car	Wrong position	Degraded fastening, degraded aesthetics	7	Operator mistake/incorrect process/incorrect design	5	SC	Visual check/Fixture	Visual check/Wetting test	5	175
				Wrong variant	Wrong variant, wrong color	7	Operator mistake/incorrect process	5	SC	JIS Supply	Visual check	2	70
3			Control correct position	Wrong position	Degraded fastening, clips breakage	4	Operator mistake/incorrect process/incorrect design	5	SC	Visual check	Visual check/Wetting test	2	40
4			Apply pressure x Pa for y seconds	Not enough pressure for enough time	Degraded fastening	5	Operator mistake/incorrect process	5	SC	Poka yoke fixture	Visual check/Wetting test	7	175

Figure 4.26: PFMEA Clips

4.5.2 Ishikawa diagram

To map the causes for quality issues, an Ishikawa diagram was executed and is presented in Figure 4.27. To deepen the risk analysis for the processes, a method to identify and address the root causes of potential failures will be carried out. The root cause analysis or Ishikawa diagram is made for the most severe risks that is being identified in the PFMEA procedure.

Engineering
The cornerstone in engineering is mainly about developing and verifying part and process requirement. This is achieved through activities such as assuring serviceability an verifying producability. Also, through cross-functional communication, designing for a specific application is essential to establish a high-quality solution.

Environment
The quality of the product can be affected by environmental conditions on the surface such as temperature, cleanliness and humidity. Also external environmental conditions such as noise, lightning, space and 5S are an indirect cause to a product's quality.

Process
The level of process supervision is crucial for the quality of the product and is one of the most important factors regarding the process' impact. The process supervision is complemented with its equipment such as consumables, maintenance and fixtures to establish the best possible process.

The time duration of the process shapes the process in terms of how much time can be spent to complete the task. Besides the time duration, the nature of the operation will also affect the quality such as how stable, monotonous and balanced the task is. This is also connected to ergonomics, both physical and cognitive.

Management
Of course, leadership is the pillar of good management and might have the greatest, indirect impact on the quality of the final product. Good leadership in combination with early supplier involvement enables proper forecasting which can facilitate handling change. A high level of design flexibility is connected to standardization and is the solution to handle late changes.

Material
The material branch in the Ishikawa analysis covers all material aspects affecting the final product's quality. Procurement and pre-assembly from the suppliers is directly connected to article complexity, which will affect the quality. Mechanical properties is the factor that affects the quality from a structural perspective and is also strictly connected to the tolerances of the part and process. The shelf life differs depending on what fastening technique is used due to the nature of the needed parts and articles.

People

The people is truly important to achieve great quality, and is connected to the process' operator dependability. However, aspects like psychosocial health, fatigue, skills, education, concentration and motivation are all affecting the outcome. This may not differs as much depending on what fastening technique that are used, but is more connected to the nature of the process and its requirements.

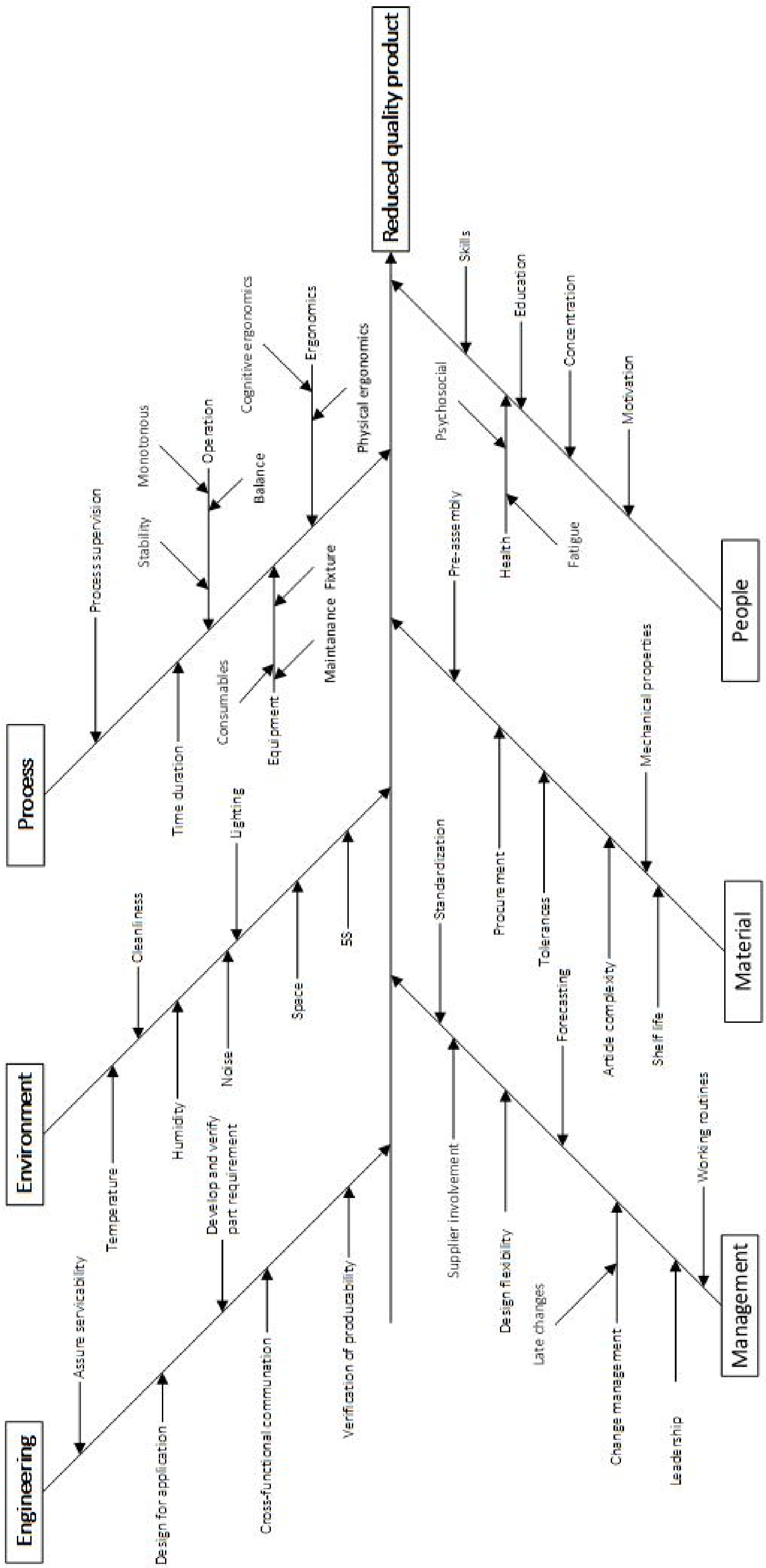

Figure 4.27: Ishikawa diagram

4.5.3 Perceived quality

The result regarding perceived quality is presented here for the adhesive tape and mechanical fasteners.

Adhesive tape
The main issue with adhesive tape is that it is hard to verify quality due to an unreliable technique and inexperienced engineers. However, if good wet-out can be achieved, taping's great potential is beyond snap-fit fasteners. In the model presented by Stylidis et al. (2015), perceived quality is divided into visual, feel, sound and smell. A taped solution improves at least three out of four of theses areas. Taping provides less noise and vibrations, and at the same time creates a visually sustainable solution with minimum play between the part and the body. The smell quality has not been considered in this study.

Mechanical fasteners
Mechanical fasteners usage leads to the opposite result from adhesive tape. Using mechanical fasteners is reliable and the car manufacturing industry is well-experienced with this method (Messler et al., 1997). The issue is that the perceived quality can be jeopardized as sink marks may appear, pouring liquids is visible, and the play between the part and the body is not optimal.

4.6 Ergonomics

By analysing the working process involving the postures when attaching a fender flare with clips or adhesive tape it is clear that the posture with the highest risk is the apply pressure to the plastic extension posture. Thus, this will be further analysed to assure that no regulations or limits are breached.

The Key Indicator Method for repetitive work (KIM III) (Arbetsmiljöverket, 2012) is used to assess the ergonomic impact for the different joining techniques. The result from the assessment is presented in Table 4.2.

	Adhesive tape	Snap-fit fasteners
KIM III score	22	15.75
Risk area	2	2

Table 4.2: The result from the KIM III analysis

The adhesive tape method scores a slightly higher than the snap-fit fasteners according to the KIM III evaluation. Both methods performs within the risk area 2 out of 4, which is approved.

4.6.1 Cognitive ergonomics

Based on observations and interviews, the mechanical fasteners are preferable from a cognitive support perspective. Mechanical fasteners have an automatic guiding in terms of holes that fits the snap-fit fasteners. It is possible to attach the extension with snap-fit fasteners without any need of tools or equipment. The snap-fit fasteners provides a click sound and a sort of feeling when it attaches which helps to operator to quality approve.

Contrary to snap-fit fasteners, adhesive tape needs equipment and tools to ensure the quality of the process. The adhesive tape roller seen in Figure 4.28 is used to assure enough pressure is being applied when attaching adhesive tape. The roller requires a certain amount of pressure to function and move over the taped surface, thus it is impossible to move without applying the right amount of pressure and provides a self-assuring pressurize control. In addition to the roller, adhesive tape require some sort of guiding pins or fixture to assure correct positioning. The cleaning of surface before attaching the adhesive tape is very dependent on the operator accuracy, thus requiring higher skill or process supervision.

Figure 4.28: Adhesive tape roller (3M, 2017)

4.6.2 DFA - Product complexity

Equation (4.1) is used to calculate the DFA index for the joining of a WAE either with snap-fit or adhesive tape fasteners. The minimum number of parts are derived from Process Instructions from CEVT and the assembly time is taken from the MTM-SAM study. The basic assembly time is approximately 3 seconds, which results in $t_a = 3$ and is equal for both methods.

$$E_{ma} = N_{min} t_a / t_{ma} \tag{4.1}$$

Snap-fit
The WAE is attached with 14 snap-fit fasteners which results in $N_{min} = 14$. With

the estimated time to assemble the product, from the time study, as $t_{ma,S} = 28.96$ the DFA index for the snap-fit fastening method is calculated as $E_{ma,S} = 1.45$.

Adhesive tape
The WAE is attached with 2 long stripes of adhesive tape which results in $N_{min} = 2$. With the estimated time to assemble the product, from the time study, as $t_{ma,T} = 44.1$ the DFA index for the adhesive tape method is calculated as $E_{ma,T} = 0.13$.

The number of different snap-fits used for the construction can vary and will affect the complexity of the product.

The WAE is often divided into two or three sections to facilitate serviceability as earlier explained, as a consequences of the tape usage.

Snap-fit fastening scenarios - WAE
As found in the competitor analysis (benchmark), the usage of snap-fit fasteners can vary extensively. The most complex solution for a WAE found in the analysis, from a DFA perspective, was the Fiat 500X (2014) with a minimum number of parts of $N_{min} = 17$ with 6 different article numbers. The best solution found in the analysis, from a DFA perspective, was the Land Rover Range Rover Evoque (2014) with a minimum number of parts of $N_{min} = 7$.

4.7 Evaluation matrix

The results from the evaluation matrix is presented here. The matrix is attached in Figures 4.29, 4.30, 4.31, and 4.32. Each category is explained and the bullet points behind the figures are highlighted. The figures are estimated and based on experiences together with a group of experts in car manufacturing. The evaluation was performed during a workshop session through discussion and elaboration. Each criteria is weighted on a scale from 1 to 5 based on its importance for the customer and then rated on a scale from 1 to 3 based on its performance for a defined case. Then the weight and rating are multiplied which results in a score for each criteria. From this, two key figures are derived for each category; a summarized score and a mean weighted score that shows the performance. This section ends with a summary of the evaluation results in the form of a graph showing the performance of both fastening methods.

Nr.	Criteria	Explanation	Weight
Category 1: Engineering			
1,1	Manufacturing engineering	To verify producability and quality in manufacturing	5
1,2	Supplier manufacturing	Manufacturing complexity and preassembly at the supplier	5
1,3	Tolerance requirements	Geometrical tolerance requirements for production to work properly	4
1,4	Design freedom	Degrees of freedom in the design phase	2
1,5	Design flexibility	Possibility to make late changes	3
1,6	Design complexity	DFA - number of parts	3.5
1,7	Material flow	Material flow and material handling requirements	1
Category 2: Production			
2.1	Repeatability	Is the process trustworthy and robust	5
2.2	Assembly time	The time it takes to perform the complete assembly	3
2.3	Quality assurance	Possibility to detect defects	5
2.5	Operator dependability	How dependeble is the process on the operator's skills	5
2.6	Process supervision	Supervision requirements of the process	5
2.7	Preparation of joint	Surface and hole requirements	3
2.8	Environmental dependability	Dependence on temperature, humidity, cleanliness	4
2.9	Ease of repair/adjust	Ease of reparation and adjustment during production	2
2,10	Cognitive ergonomics	Cognitive help during assembly	5
2,11	Equipment	Tools and fixtures in need of maintenance etc	3.5
2,12	Consumables	Wipers, detergents, liquids etc required for production	3
2,13	Health and safety	Health and safety risks during production	5
2,14	Physical ergonomics	Physical ergonomic evaluation of the assembly process	4.5

Figure 4.29: Category 1-2 explanation

Category 3: Final product - Performance parameters			
3.2	Strength of bond/peeling resistance	How strong is the bond, required pull-off force, peel-off force	5
3.3	Temperature resistance	Resistance against temperature changes	2
3.6	Perceived quality	The perceived quality of the detail	5
3.7	Noice vibration harshness (NVH)	The ability to withstand noice, vibrations and shear loading over time	5
3.8	Coldshock absorption	The ability to withstand coldshocks	5
3.9	Strength to weight ratio	Strength to weight ratio	2
3,10	Corrosion resistance	How is the corrosion resistance	3
3.1	Solvent resistance	Part resistance towards solvents	5
3.1	Sealing function	The ability to seal from dirt and moisture	5
Category 4: After market			
4,1	Quality of reattached joint	Durability and reliability of the reattached joint	5
4,2	Ease of removal	How easy it is to remove the part	4
4,4	Ease of reattaching	How easy it is to reattach	4
4,6	Possibility to reuse part	Is it possible to reuse the part	4
4,7	Possibility to recycle part	How easy is it to recycle the part	2
4,8	Merchandise	Availability of spare-parts and accessories	2
4,9	Do it yourself	The possibility to perform reparations by yourself	2

Figure 4.30: Category 3-4 explanation

		Acrylic foam tape			Mechanical fasteners		
Nr.	Criteria	Motivation	Rating	Score	Motivation	Rating	Score
Category 1: Engineering							
1,1	Manufacturing engineering	Moderate grade of experience in ensuring quality	2	10	High grade of experience in ensuring quality	3	15
1,2	Supplier manufacturing	Moderate complexity and preassembly requirements	2	10	Moderate complexity and preassembly requirements	2	10
1,3	Tolerance requirements	Moderate requirements on parallell tape planes and shear loading	2	8	Moderate requirements on hole geometry and tolerances	2	8
1,4	Design freedom	High freedom of design due to no hole requirement	3	6	Hole requirement reduce design freedom	2	4
1,5	Design flexibility	High possibilities to make late changes due to no hole requirement	3	9	Hole requirement needs to be defined in early phases	1	3
1,6	Design complexity	Low number of parts	3	11	Moderate number of parts	2	7
1,7	Material flow	No noticeble effect on material handling	2	2	No noticeble effect on material handling	2	2
		Summarized score		56	Summarized score		49
Category 2: Production		Mean weighted score		8	Mean weighted score		7
2.1	Repeatability	The process is complex to quality assure and verify	1	5	The process is robust and easy to quality assure	3	15
2.2	Assembly time	Requires a moderate amount of time compared to mechanical fast.	2	6	Requires a low amount of time compared to adhesive tape	3	9
2.3	Quality assurance	Very hard to detect defects after assembly	1	5	Moderate possibilties to detect defects after assembly	2	10
2.5	Operator dependability	Very dependent on the skill of the operator	1	5	Simple process not dependeble on the operator skill	3	15
2.6	Process supervision	Requires supervision to assure quality	1	5	Does not require supervision to assure quality	3	15
2.7	Preparation of joint	Requires preparations as in surface cleaning and drying	1	3	Requires preparations as in hole generation	1	3
2.8	Environmental dependability	Very dependent on external environmental factors	1	4	Moderately dependent on external environmental factors	2	8
2.9	Ease of repair/adjust	Very hard to adjust/repair after assembly	1	2	Moderately hard to adjust/repair after assembly	2	4
2,10	Cognitive ergonomics	Moderate cognitive help from fixture and/or guiding pins	2	10	High level of cognitive help from clips and holes	3	15
2,11	Equipment	Requires fixtures and tools to assure quality	1	4	No equipment requirements	3	11
2,12	Consumables	Requires wipers and liquids to prepare surface	1	3	No consumables needed	3	9
2,13	Health and safety	No noticable health and safety risks (assume no primer)	2	10	No noticable health and safety risks	2	10
2,14	Physical ergonomics	No noticable physical ergonomics risks	2	9	No noticable physical ergonomics risks	2	9
		Summarized score		71	Summarized score		133
Category 3: Final product - Performance parai		Mean weighted score		5	Mean weighted score		10

Figure 4.31: Category 1-2 rating and motivation

Category 3: Final product - Performance parar		Mean weighted score		5	Mean weighted score		10
3.2	Strength of bond/peeling resistance	High strength of bond, moderate peel-off force	2	10	High strength of bond, moderate peel-off force	2	10
3.3	Temperature resistance	Moderate temperature resistance	2	4	Moderate temperature resistance	2	4
3.6	Perceived quality	High perceived quality due to no visible attachment marks	3	15	Moderate perceived quality due to possible sink marks and play	2	10
3.7	Noice vibration harshness (NVH)	Good ability to withstand NVH due to tape function	3	15	Extra sealing functions must be added to withstand NVH	2	10
3.8	Coldshock absorption	Moderate coldshock resistance due to flex properties	2	10	Good ability to withstand coldshocks due to less temp dependent	3	15
3.9	Strength to weight ratio	High strength in relation to weight	3	6	Moderate strength in relation to weight	2	4
3,10	Corrosion resistance	No holes needed, therefore good corrosion resistance	3	9	Holes needed, therefore moderate corrosion resistance	2	6
3.1	Solvent resistance	Tape might get affected of solvents	2	10	Clips does not get affected by solvents	3	15
3.1	Sealing function	Sealing function integrated for the adhesive tape	3	15	Sealing must be added to achieve good properties	2	10
		Summarized score		94	Summarized score		84
Category 4: After market		Mean weighted score		10	Mean weighted score		9
4,1	Quality of reattached joint	Very hard to assure high quality of reattached joint	1	5	High quality of reattached joint	3	15
4,2	Ease of removal	The tape is very hard to remove	1	4	Part attached with clips is easy to remove	3	12
4,4	Ease of reattaching	The tape is complex to reattach, high level of knowledge needed	1	4	Part attached with clips is easy to reattach	3	12
4,6	Possibility to reuse part	Not possible to reuse a taped part	1	4	Part attached with clips can be reused up to several times	3	12
4,7	Possibility to recycle part	Tape must be separated from part to recycle	2	4	Clips must be seperated from part to recycle	2	4
4,8	Merchandise	Moderate availability of spare parts to tape	2	4	Moderate availability of spare parts to clips	2	4
4,9	Do it yourself	Hard to perform reparations by yourself	1	2	Moderate knowledge needed to perform reparations by yourself	2	4
		Summarized score		27	Summarized score		63
		Mean weighted score		4	Mean weighted score		9
		Total summarized score		247			329
		Total mean score		28			36

Figure 4.32: Category 3-4 rating and motivation

4.7.1 Engineering

The score for the Engineering category is relatively similar between the two fastening methods. For criteria 1.2, 1.3 and 1.7 regarding manufacturing complexity, geometrical tolerances and material flow, both taping and mechanical fasteners scores a moderate rating due to neither one of them is affected that much of the choice of fastening method.

Taping scores higher than mechanical fasteners for criteria 1.4, 1.5 and 1.6 regarding design freedom, design flexibility and design complexity, which is a result of less physical restrictions when designing for a taped solution.

However, criteria 1.1 regarding verifying producability and quality in manufacturing is the the criteria with the highest weight, and is scored highest by the mechanical fastening method. The mechanical fastening is the method where most knowledge and experience is found in the automotive industry, which is why this process is more ensured and qualified.

During the engineering phase, the lack of consensus and conflicting interests leads to no existing common ground between R&D's design division and R&D's Manufacturing Engineering division. When the product is ready for production, and yet no consensus is reached, technical and ergonomic issues may arise which generates quality issues on the final product.

For category Engineering, adhesive tape scores the better mean weighted score of 8 compared to mechanical fasteners' 7, as shown in Table 4.3.

	Adhesive tape	Mechanical fasteners
Summarized score	56	49
Mean weighted score	8	7

Table 4.3: The Engineering result

4.7.2 Production

The score for the Production category differs extensively between adhesive taping and mechanical fasteners.

With highest possible weight and at the same time dominated by the mechanical fastening method, criteria 2.1, 2.3, 2.5, 2.6, 2.10 regarding robustness, defect detection, operator dependability, process supervision and cognitive ergonomics, are the main reason why the fastening methods are differing this much.

For lower weighted criteria such as 2.2, 2.8, 2.9, 2.11, 2.12 regarding assembly time, environmental dependability, adjustment possibilities during production, equipment and consumables, mechanical fasteners still scores the highest due to a more stable process with less additional requirements.

Criteria 2.7, 2.13 and 2.14 are the only ones where adhesive taping and mechanical fasteners scores the same, which are regarding surface and hole requirements, health risks and physical ergonomics. These are the criteria where no noticeable difference have been identified, which result in an equal score.

For category Production, mechanical fasteners scores the extensively highest mean weighted score of 10 against adhesive tape's 5. The score for this category is presented in Table 4.4.

	Adhesive tape	Mechanical fasteners
Summarized score	71	133
Mean weighted score	5	10

Table 4.4: The Production result

4.7.3 Final product

Just as the first category, Engineering, the third category Final product scores similar between taping and mechanical fasteners.

For criteria 3.2 and 3.3 regarding bond strength and temperature resistance both fastening methods scores a moderate rating for where the first one is of higher weight. Both methods scores moderate due to high strength of bond but still a quite high peel-off force. These are the only criteria where the methods scores equally for category Final product. The rest is distributed on the two fastening methods for every other criteria.

For criteria 3.6, 3.7, 3.9, 3.10 and 3.12 regarding perceived quality, noise and vibration, strength to weight ratio, corrosion resistance and sealing function, taping scores higher than mechanical fasteners. This is mainly due to better design functions with less complexity in adhesive taping.

Mechanical fasteners scores higher than taping in criteria 3.8 and 3.11 regarding cold shock absorption and solvent resistance due to its mechanical characteristics. Mechanical fasteners scores high on important criteria, but it cannot stop taping from scoring the highest over all score for category Final product. With a mean weighted score of 10, adhesive tape beats mechanical fastener's score of 9 as shown in Table 4.5.

	Adhesive tape	Mechanical fasteners
Summarized score	94	84
Mean weighted score	10	9

Table 4.5: The Final product result

4.7.4 After market

Like the second category, Production, the fourth and last category regarding the after market differs a lot between taping and mechanical fasteners.

Criteria 4.7 and 4.8 regarding recycling and merchandise are the only criteria where adhesive taping scores the same as mechanical fasteners. This is due to no sign of difference has been identified between the two methods.

The rest of category After market is dominated by mechanical fasteners. Criteria 4.1, 4.2, 4.4, 4.5, 4.6 and 4.9 regarding quality of re-attached joint, ease of removal and re-attachment, re-usage and do it yourself, is scored the highest by mechanical fasteners. Adhesive taping is facing major problems in the after market due to its limited possibilities of re-attaching and re-using the part. Replacing parts attached with adhesive bonding is generally more complicated to replace than a mechanical attached one. When a taped part is removed it cannot be re-used, due to that the aggressive method of removal will most probably damage the part itself (Tuve Skadecenter Workshop, 2017). After removal, the surface must be cleaned and sometimes go through a grind process. This results in a complex and expensive service process and observations made during the study visit to Tuve workshop fortifies this dilemma. The technician explains that there are issues regarding the ability to properly remove a plastic exterior extension without causing any defects on the part itself. It is also an issue that adhesives tend to stick to the surface on both the plastic extension and the car body, thus is troublesome to remove without needing detergents to clean the surfaces.

As shown in Table 4.6, mechanical fasteners scores a mean weighted score of 9, compared to taping's 4, which is a huge difference between the two methods. Compared to a taped part, a snap-fit fastened part can be re-used. The part is simply removed with a pull-off force, which will break the snap-fits. The snap-fits are replaced and the part can be attached back to the car again. No need of cleaning the surface or scrap the part (Tuve Skadecenter Workshop, 2017). Compared to adhesive tape, this service process is less complex and less expensive.

	Adhesive tape	Mechanical fasteners
Summarized score	27	63
Mean weighted score	4	9

Table 4.6: The After market result

4.7.5 Summary

As expected, the methods performs differently in all categories. The performance of the mechanical fastening method is well spread out over all categories and represents an even and trustworthy process, as shown in Figure 4.33. The adhesive taping method, however, performs high in Engineering and Final product but less satisfying in the Production and After market category.

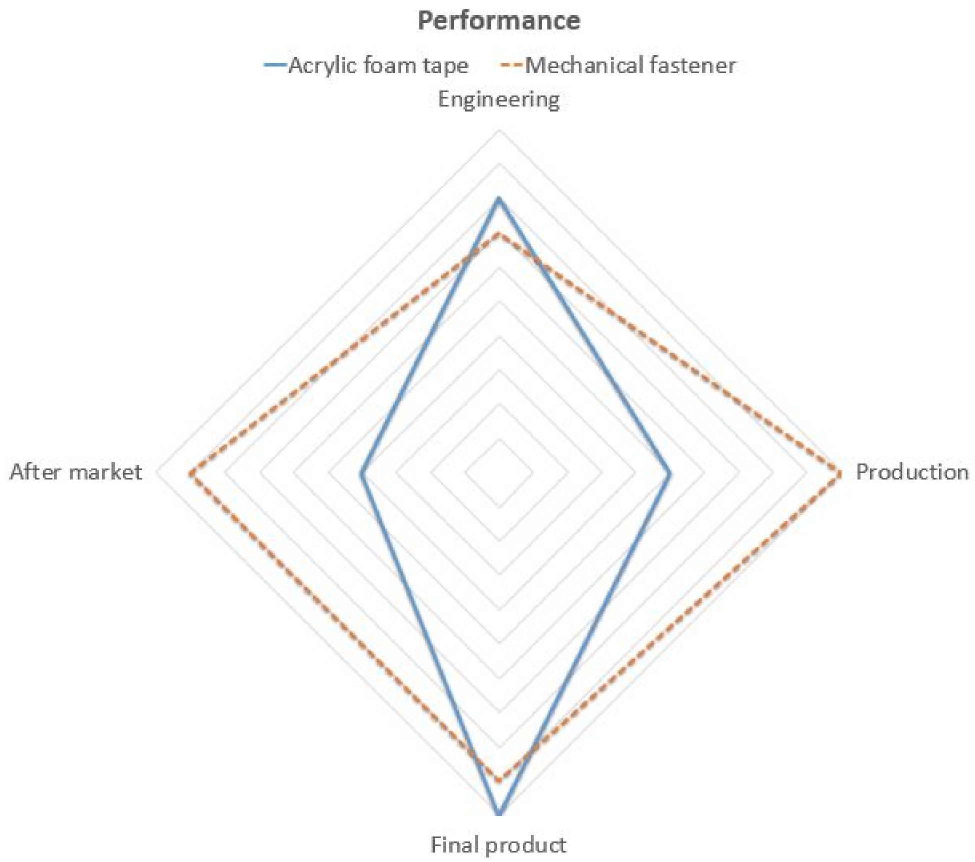

Figure 4.33: Performance of the fastening methods

5

Discussion

In the fifth chapter of this thesis, the results shown in the analysis is discussed and explained to provide the reader with a critical outlook. It is meant to explain the project results in terms of validity and reliability as well as motivate all necessary assumptions. The feasibility of the methodology throughout this project and its connection to the given results is discussed as a start. Further on, the four research areas, economy, time, quality and ergonomics including the implication of engineering tools such as MTM-SAM, PFMEA, Ishikawa diagram and KIM III are evaluated. The evaluation matrix and its corresponding results is reviewed in a critical manner to give the reader a deeper understanding of its meaning. Conclusively, suggestions on further research is made.

5.1 Methodology

This section aims to discuss the feasibility of the chosen methodology used throughout this project. The methodology was divided into three phases starting with the learning phase, followed by the identification phase and ending with the evaluation phase. Each phase was built upon different activities to reach the desired objectives.

The learning phase started with learning about the issue by defining a reachable scope and suitable objectives for the project. Then the data collection started and we made contact with and interviewed many skillful people from different branches of the automotive industry. Both informal and formal semi-structured interviews with open questions have been made with specialists and generalists in the automotive sector to gain a holistic understanding of today's attachment techniques. Additional meetings with suppliers and sub-component manufacturers, observations during field visits at an OEM production site resulted in a very broad base of qualitative data.

Later on, the identification part was initiated and a set of product groups, engineering tools, research areas and technical criteria to evaluate was identified. A structured way of working according to the process selection model when assessing the collected data and technical regulations assured a valid outcome.

During the last step of the project, namely the evaluation phase, the engineering tools were assessed and categorized into several research areas. The produced technical criteria were categorized into different phases of the product flow that created the evaluation matrix consisting of four phases as in engineering, production, final product and after market.

The triangulation strategy made out of literature, quantitative and qualitative data is not complete in all senses due to the absence of quantitative data available for this study. The lack of historical data and quality statistics primarily because of CEVT's situation of being a newly developed company without a production site in Sweden made this project focus on qualitative data in more general way.

5.2 Competitor analysis

The competitor analysis illustrates how a majority of today's cars uses mechanical fasteners for plastic car body extensions. Only a few competitors uses adhesive tape together with mechanical fasteners. No one relies completely on adhesive tape when it comes to fender flares, rocker panels or door side moldings. With this said, the diversity of technical fastening solutions are quite small although it differs greatly when studying the details. Every car producer and every car model has its own fastening solution with specially designed snap-fit fasteners. The part complexity, the number of unique parts varies considerably between different car models.

The competitor analysis shows how today's cars have been built up until today and a historically time interval of five years back. It is important to note that the competitor analysis only consider the past and thus do not show any trends of the future. With this said, future fastening technologies that may arise are still an unanswered question. The analysis is also greatly biased by the work of A2MAC1 and the pictures as well as descriptions provided on their website. The analysis covers 15 different car models, which is not enough to draw conclusions of the whole industry. It is possible to reach a higher validity of the competitor analysis by looking into more cars and do independent reversed engineering projects.

The car model Seat Ateca uses adhesive tape for the fender flare extensions and are in this way an adhesive tape pioneer when compared to others. It is the only car model that solely uses adhesive tape for the attachment of a fender flare. Generally, the design of the plastic extensions differs greatly between the competitors. Volvo have a more complex designs for their plastic extensions with two separate parts merged together, one front part and one backing part. Seat on the other hand, have a very straight forward and much more simple design for the fender flare, a design that is possible without the need of clips houses.

Conclusively, there are no standards when it comes to the fastening of plastic extensions. Every car producer and car model has its own customized design solution.

The part complexity and attachment technique are always customized to fit the design of the car.

5.3 Cost model

The purpose of the cost analysis is to highlight relative differences between the attachment methods and important cost drivers. Thus, the cost calculation results of the fictive case shows that adhesive tape requires higher investments due to it being a more technologically advanced process with more process steps and higher operator skill requirements. It also requires about two times larger area than a snap-fit fastener assembly because of the adhesive tape process being more time demanding than snap-fit fasteners and with a continuously moving line, the car covers more ground the longer the process. Once again it is important to point out that the calculations are based on well functioning processes where quality problems and production instability have been neglected.

Since the labor costs are based on Chinese wages, conclusions can only be drawn for manufacturing located in China where the labor costs are relatively low compared to the western world. Setting up the same production plant in Sweden would probably result in a higher grade of automation and a lower grade of manual manual work due to higher wages. In this regard, developing a production plant in China will most likely lead to an increase of manual assembly and thus higher dependency on the operator skills. Since adhesive tape is a more complex and requiring process it is clearly a disadvantage to use in a highly manual assembly. Snap-fit fasteners are much easier to handle manually, and in the case of China therefore have several advantages and will be the recommended attachment technique when it comes to the economical aspect.

ABC allocation of overhead costs that is introduced in the theory section can make the cost calculations of overhead costs much more accurate. To do this, information regarding time spent on certain activities is needed. It is also necessary to know about the total costs from a historical perspective to enable an accurate distribution. Most costing models are based on costing on a higher system level, for instance on a plant level where . Concerning this, this model has some drawbacks since it is difficult to adapt a system level cost model to fit a specific part production and assembly station. Additionally, the time period for the cost calculations greatly affects the result, and due to the car industry being in a relatively volatile market, most cost calculations are made with respect to a short time frame.

The distribution and relative effect of cost factors depends a lot on the production volume. A low production volume leads to relatively high factory expenses and general expenses when compared to direct costs, as can be seen in figure 5.1 below with variable expenses and fixed expenses. On the other hand, a car manufacturing factory with production volumes of thousands of cars has a very high volume. Thus, the relevant costs in the car production scenario are the direct material and direct labor costs which is dependent on the volume produced. The direct material and direct labor increases linearly with the capacity as seen in figure 5.1.

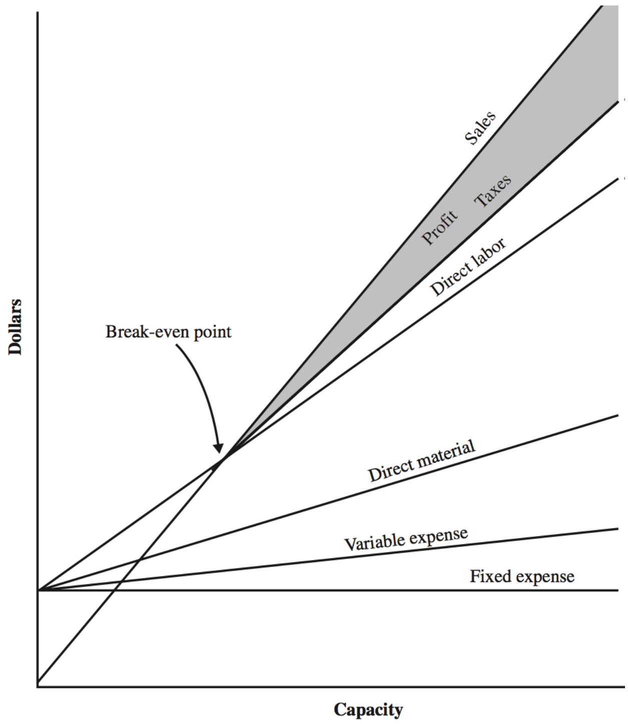

Figure 5.1: Cost graph

This cost model will serve as a template for future scenarios and comparisons of attachment techniques. It provides a holistic picture of what costs to include and how one can examine if a possible investment pays off or not. It also enables direct comparisons of different cost factors and how they affect the end result. It is possible to adjust the figures to fit different scenarios.

5.4 Time study

The predetermined time system SAM was used to analyze assembly work, which is a well-established and accepted method within Swedish and global industry. However, there are other options when it comes to pretermined time systems such as MTM-1, MTM-2 and MTM-3. The main issue with these methods are the required analysis time, that can be up to 250 times as much as the actual assembly time (Freivalds and Niebel, 2009). Comparing this to SAM, where the relation is 30 times as much time for the analysis to the assembly time, makes it the most suitable method to use.

The time study is based on a theoretical production, not real practise, since CEVT's production is not up and running yet. This means that the analysis is based on a "perfect" process, which in reality does not exist. A production and its processes always includes mistakes and failures, in which continuous improvement work is used to solve. A more accurate analysis would be to analyze real production time and compare it to the theoretical time study to highlight areas for improvement.

The time study compares three different fastening methods; tape, snap-fit fastener and a hybrid fastener. As mentioned before, the methods are theoretical and does not exist in reality. The hybrid is a combination of tape and mechanical fastener time study. The sequence and magnitude of the operations is established through discussion with experts and what has been seen in study visits. This means that the time study is based on qualified estimations with input from experts and empirical data. Since the study is based on estimations, the time study serves as a guide, not an exact calculation of the assembly time.

Important to mention is that the time study is applied on a specific case and there are other options to perform the operation as well. And since no optimizations have been performed, it is difficult to state which process have the most potential from this aspect.

5.5 Quality

The quality analysis consisted of performing PFMEA, evaluating perceived quality and to develop an Ishikawa diagram, which all are discussed further in this section.

The figures in the PFMEA's are all estimations from experienced workers at CEVT in combination with the result in this work. The PFMEA highlights the areas with the highest and most likely failure mode and what effects there are. The result from the PFMEA is based on the RPN score which is the multiplication of Severity, Occurrence and Detection. However, if several operations ends up on the same RPN score, another factor must be considered, which in almost all cases should be Severity. As in the PFMEA case on adhesive tape, four processes ended up on the same RPN score, the Severity score must be prioritized. In this case Severity, Occurrence and Detection had all the same score, therefore no further conclusions can be drawn.

Depending on the type of defect and service that is required due to a quality issue, the responsibility for costs and warranty can differ. Warranty is directly connected to a car producers costs and thus of interest to look into. When a plastic extension looses its grip due to some reason, it is granted by warranty. On the other hand, When a plastic extension needs to be removed or scrapped due to enable reparation of a bumper, it is covered by warranty.

The result from perceived quality is mainly derived from the evaluation matrix and by interviews. Since perceived quality has not been the main focus of this study, it is more like a spin-off from the main result. As stated in the analysis, taping is preferable from a perceived quality perspective. However, since no physical test has been performed, the smell quality area is neglected.

An Ishikawa diagram was developed to analyze the problem from a more holistic point of view and to enable highlight areas of cause. The diagram and its causes are brainstormed as a result from the research in this study. In Figure 5.2, three areas are highlighted; process, engineering and management. These are the main areas of cause that has been identified affected the quality of the final product.

In today's situation, using tape is seen as an emergency solution. It has been understood, from interviews, that tape is treated as the problem. Yet, tape is not the problem. Tape is the indication but the main problem is late changes and is a cause of bad change management. When a late change is to be implemented and the current solution is designed for snap-fit fasteners, the cheapest and easiest way is to use tape since it does not require making new holes. New holes are expensive to add late in the development phase if the stamping tool already is made. Late changes is discussed further in the section "Further research suggestion".

It has also been identified that influences from engineering and the actual process lays as causes to bad quality when using tape. Design for application is crucial to achieve high quality and especially to avoid late changes. Cross-functional communication enables developing and verifying part requirement and its producability, which is not always the case today. Departments within the organizations have trouble reaching consensus due to bad communication and no united knowledge, which leads to bad quality products.

The tape's process is also one reason to decreased quality. The knowledge and experience is not equal to snap-fit fasteners, which leads to a less ensured process. The tape process needs more supervision, time, space and equipment than snap-fit fasteners to ensure the same quality.

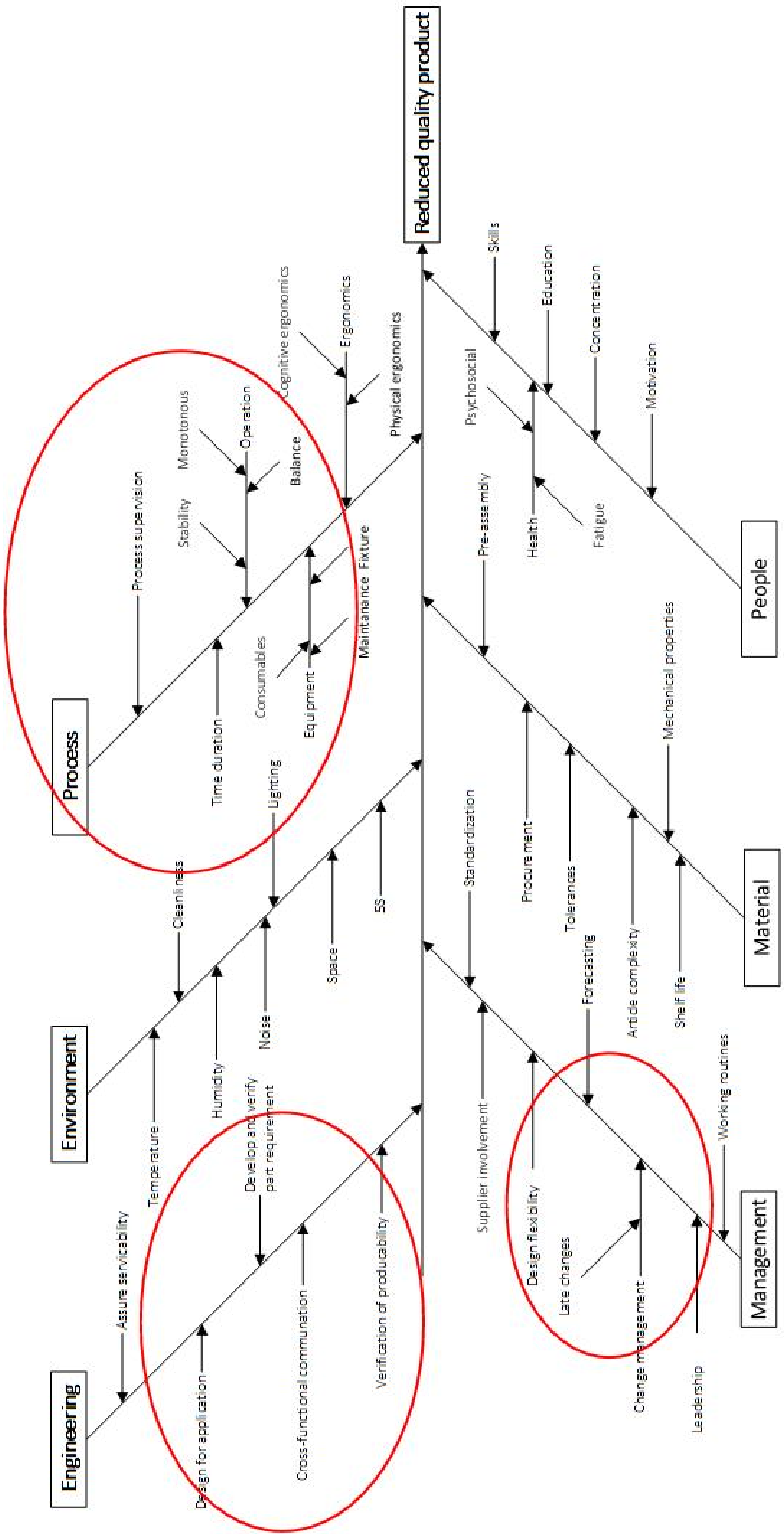

Figure 5.2: Ishikawa diagram with highlighted areas of cause

5.6 Ergonomics

The difference in the ergonomic evaluation KIM III is not extensive between the fastening methods. Since both methods performs within the same risk area, no further analysis is made. The evaluation is made on a theoretical case, the same as used in the time study, which decreases the validity of the result. Preferably, a real production case should be evaluated, but could not be done since it does not exist yet.

Efficiency and motivation decreases when too much information is spent on finding relevant information. Frequently used information should be easily accessed and emphasized. Snap-fit fasteners are better from this perspective, especially auditory, where clear distinguishable sounds are built in. When using adhesive bonding in production, more equipment and tools are essential to reach the same cognitive support such as fixtures or guiding pins, and yet there is no physical conformation of correct assembly as for snap-fit fasteners. However, there are theories that the reduced cognitive support from the use of adhesive tape should be no problem in terms of final quality. "Trust the operator and he/she will do a great job", says Marcus Johansson at Manufacturing Engineering from Volvo.

One part of the ergonomics analysis has been a DFA comparison, mainly to evaluate the complexity between the attachment methods. The limitation with DFA comparison is that it only considers the design and not the actual attachment process. Furthermore, tape is better from a DFA perspective due to less complex design with less parts, compared to mechanical fasteners. However, to ensure a good assembly, tape is in need of more tools and equipment such as fixtures, wipers etc., which make the process more complex.

5.7 Evaluation Matrix

The evaluation matrix is an essential part of the results since it is a framework that tie together the whole project with all its subsidiaries. The categories are based on the product flow to establish a red thread and facilitate the understanding of its ingoing criteria. Assigning weights and scores to the criteria helps the assessment team to put the customer satisfaction in focus. It is possible for engineers to modify the weights to alter different situation which affects the final outcome if the initial state does not agree with the desired outcome. With this in mind, the whole matrix including the assignment of weights and scores is subjective and largely based on the opinions and experiences of the assessment team. In this project, the assessment team consisted of one homogeneous group of people from CEVT Manufacturing Engineering department. Thus, there is a chance that the results got biased and to reach a higher validity, other people with alternative backgrounds are required in the assessment team.

An evaluation matrix of this sort could possibly overlook the real problem by concentrating on details as in certain criteria of little significance. Therefore, it is important to find the right scope and problem definition before starting to create a set of criteria and then assign weights and scores. No perfect design for evaluations exists since all evaluations involve trade-offs and are heavily dependent on the circumstances. Instead, the matrix is an organizing tool to plan for the evaluation. It effectively organizes evaluation questions and facilitates collecting information to answer questions and sub-questions. It guides the audience through the analysis and brings all the mixed-methods sources together in a structured way.

The results of the evaluation matrix shows that adhesive taping is far more complex and uncertain in the production and after market phase while it still has the possibility to achieve the best rating when it comes to final product characteristics and flexibility in design. Contrary to this, the snap-fit fasteners remains a reliable and stable process in production, but lacks some opportunities in the engineering phase. It is possible that adhesive tape as an attachment technique in car manufacturing suffered some points since it is less proven. The snap-fit fasteners solution is very well proven and the assessment team got lots of experience in the snap-fit fasteners area and one should be aware of that people tend to vote for the more familiar technique which could affect the snap-fit fasteners rating in a positive way.

5.8 Societal, ethical and ecological issues

CEVT is a development centre, owned by the Geely group, with all production plants located in China. The Chinese car market is the biggest passenger car market in the world, with a total sales of 21.1 million passenger cars in 2015 (Forbes, 2015). That is an increase with 7.3% from 2014 (Forbes, 2015) and yet a massive difference compared to Sweden's total sales in 2016 of 388,000 passenger cars (Centralbyrån, 2015).

Developing cars to a market this big will indirectly affect the society in several ways. With innovative and new technologies, a new pattern of energy production and consumption will arise, as well as changes in social behaviour and lifestyle. New ways of owning and using a car, such as sharing and leasing, are concepts of CEVT's future strategy (Lynk, 2016).

As the demand is increasing along with the globalization of the automotive industry in China, requirements on the work environment will be stricter. New jobs will be created and a good work environment, in terms of ergonomics and psychosocial aspects, is essential for a sustainable production. This thesis may not affect these issues directly. However, it may serve as a basis for change in the future. This thesis will not analyze societal issues anymore than this paragraph, but its importance of indirect influence is crucial to mention at this stage.

Preservation of the highest ethical standards is vital in conducting an independent evaluation. There are four main issues to consider regarding ethics in project work, which are invasion of privacy, lack of informed consent, deception and harm to participants (Bryman and Bell, 2015). To ensure the interviewees' privacy is not be invaded, they will be given the option to be anonymous in this report. To prevent deception, they will be informed about the purpose of the study in advance, and what the results will be used for. As with respect to the issues of consent and harm to the participants, permission will be asked to record each interview, after which the interviews is transcribed and sent back to the interviewees to comment or take back statements.

The car industry today contributes to pollution and contamination on a considerable scale both locally and globally (McKinsey, 2016). This project will work as a cornerstone in developing and improving this company's cars for future young generations. This thesis will not directly focus on any ecological issues since it is out of the scope that is ordered by the company. Nevertheless, the work will indirectly affect the ecological ecosystem in several ways. By improving the quality of cars, the durability increases and so does the long-term sustainability. The utilization of cars will rapidly increase with the introduction of smart networks and shareable cars (Lynk, 2016). The proposed solutions in this thesis will strictly follow all regulations and recommendations for toxic substances. Swedish law and Chinese law has its differences when it comes to toxic regulations and thus a substance that is allowed in China can be forbidden in Sweden and conversely. Although, this project aims to find solutions that are allowed both in Sweden and China.

The ongoing electrification and paradigm shift in the car industry are critical to attain a more sustainable ecological ecosystem (McKinsey, 2016). The results of thesis will support this company in succeeding with necessary changes and to stay profitable and competitive to survive future challenges.

5.9 Suggestions on further research

One of the main reasons for insufficient and costly manufacturing solutions and bad experiences is when adhesive tape is being used as an emergency solution when there are no holes to attach mechanical fasteners. Emergency solutions tend to arise when plans do not align and late changes becomes inevitable. In this scenario, a well functioning process handling the new changes is usually not in place and neither is the time necessary to create it. 5.3 clearly shows how the change flexibility decreases with time while the costs for making a change increases with time.

The quality issues with adhesive tape are the symptoms of the problem that late changes causes to arise. The following questions needs to be considered for future decisions since it all comes down to a road crossing. Are we completely addicted to late changes, then go with adhesive tape since it provides extraordinary flexibility options if a well functioning taping process is in place. Or, is it possible to change the working routines towards a more stable design that has no needs for late changes, then go with snap-fit fasteners since it is the cheapest and most robust attachment alternative. For instance in CEVT's case, who are in an early development phase of the company where late changes almost always are necessary. If market trends in the future and the car life cycles becomes shorter and more volatile then the need of flexible attachment technique may be relevant, thus tape is highly relevant in this setting. Both R&D and Manufacturing Engineering has its contradictions and priorities which results in different drivers and core values. R&D strives for flexibility and new innovative in design, shorter life cycles and daring technological solutions. Manufacturing Engineering on the other hand, strives for robustness, cost reduction and standardization in manufacturing.

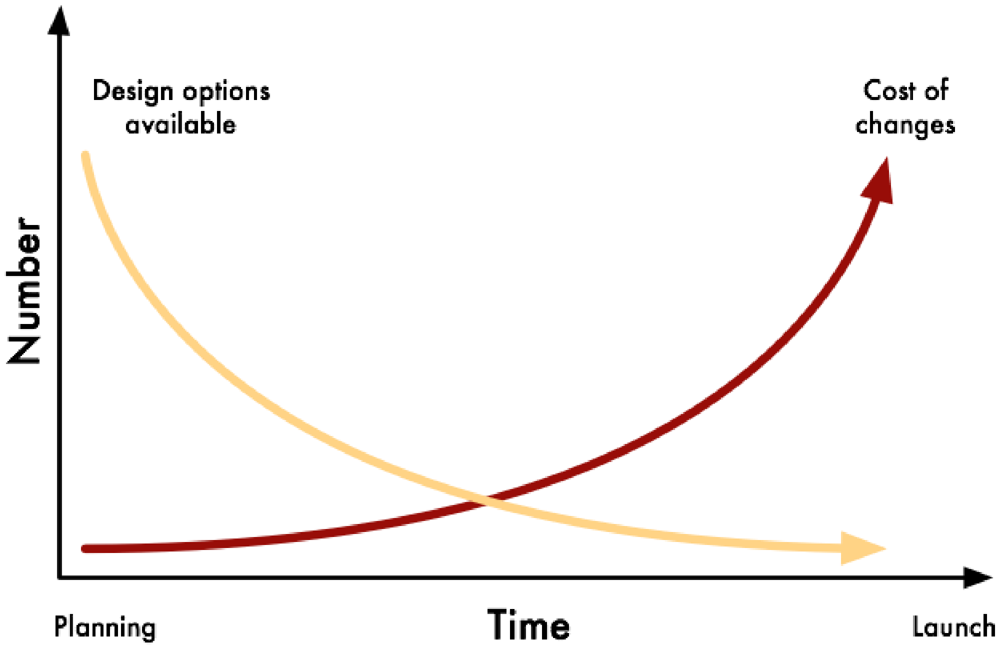

Figure 5.3: Cost of change (Liker and Meier, 2006)

As a recommendation for further research, proper working routines to ensure quality throughout the whole value chain and customer satisfaction is vital to succeed. An established structural approach to assess quality is a requirement to guarantee an end product with desirable characteristics. When it comes to the selection and development of joining techniques it is of high importance to prepare and design for a certain joining technique at the start of the design process. Thus involving, Manufacturing Engineering in the early phases and avoid late changes lead to higher costs as seen in Figure 5.3.

The evaluation including the evaluation matrix, the cost model as well as other deliveries developed throughout this thesis, represents a framework for technological comparisons that can be used for many purposes. The methodology of defining research areas and applying engineering tools to process data can be further developed to fit other scenarios as well. By adapting figures and criteria one can perform comparisons of different manufacturing techniques in many industries.

As this project has been covering the Wheel Arc Extension, all figures are based on this specific case. Hence, the validity of the results in this thesis is only certain for this. By iterating and altering the process selection procedure, according to the PDCA philosophy (Johnson, 2002), one can refine the framework to even greater extents.

6
Conclusions

From the objectives and research questions described in the introduction are the following set of conclusions that have been reached in the project. This final chapter aims to provide the reader with short but extensive information of this project's findings by answering the research questions stated in the introduction.

RQ1 - How are mechanical attachments and adhesive taping used for joining exterior car body parts in car manufacturing?

The competitor analysis in addition to observations at Volvo Cars shows that a majority of today's car manufacturers uses mechanical attachments for joining exterior car body parts. A minority group of pioneers combines mechanical attachments with adhesive tape for wheel fender flare extensions. The process mapping shows that adhesive taping is a more complex and time demanding process in production when compared to snap-fit fasteners. It is also clear that every car manufacturer has its own fastening solution specifically designed for their own cars, thus, no real standard can be identified when studying the use of snap-fit fasteners and/or adhesive tape today.

RQ2 - How can the evaluation of mechanical attachment and adhesive taping in car manufacturing be modeled?

A set of research areas consisting of quality, time, cost and ergonomics form the basis of the analysis. Each area is evaluated both qualitatively and quantitatively with the aid of engineering tools. Accordingly, an evaluation matrix consisting of technical criteria is built on the findings from each research area and quantified together with a group of experienced engineers. To test the findings, the evaluation matrix and engineering tools are applied on a specific case, namely the fender flare extension.

RQ3 - For a defined case, what are the strengths and weaknesses with mechanical attachments and adhesive taping?

For the fender flare extension case, adhesive taping performs, with a small margin, better than mechanical fasteners in the Engineering and Final product categories because of an unrestrained and flexible design process with a high quality final result, if a mature process is assumed. Yet, mechanical fasteners performs extensively better than adhesive tape in the Production and After market categories due to its proven and well-known process that requires less manufacturing preparations.

RQ4 - What are the prerequisites to ensure a successful joining process of exterior car body parts?

To map the prerequisites for a successful joining process, a framework consisting of guidelines for respectively snap-fit fasteners and adhesive taping is created. The guidelines represents a summary of all learnings and experiences throughout this project work and the purpose is to provide this project's stakeholders with recommendations for future process selections.

7

Guidelines

In this last chapter, guidelines associated to adhesive bonding and mechanical fasteners that has been developed during the thesis will be presented in the form of design considerations and common quality issues.

7.1 Adhesive bonding

Design considerations that needs to be considered regarding adhesive bonding are presented below:

- It is important to seek for a design which is completely aligned in such a way that no tension can occur between the part and the taped surface
- Joints should be designed to operate in shear, not in tension or compression
- Excessive joint overlap increases the stress concentrations at the joint ends
- The length of the lap joints should be approximately 2.5 times that of the thinnest part for optimum strength (Swift and Booker, 2013)
- The joint strength can be improved by increasing the width of the lap, adhesive thickness or increasing the stiffness of the parts to be joined
- Adhesives can be used to provide electrical, sound and heat insulation (Swift and Booker, 2013)
- Can provide a barrier for galvanic corrosion prevention between dissimilar metals or to create a pressure-tight seal (Swift and Booker, 2013)
- Jigs and fixtures should be used to maintain joint location during assembly
- Clips results in a small bulges that could cause tension such that the adhesion

for the adhesive tape is worsened. Or when the chassis has a curved body and a plastic list is mounted along this curved body, cleavage will occur at the ends of the list due to static tension

Quality considerations regarding adhesive joining are presented as follows:

- Dissimilar materials can cause residual stresses on cooling due to different expansion coefficients
- Problems are encountered with materials that are prone to stress cracking, water migration or low surface energy (Swift and Booker, 2013)
- Stress distribution over the joint area is more uniform than other joining techniques
- Joint fatigue resistance is improved due to inherent damping properties of adhesives to absorb shocks and vibrations (Swift and Booker, 2013)
- Adhesives usually have short shelf-life
- Control of surface preparation, adhesive preparation, assembly environment and hardening procedure is important for consistent joint quality
- Joint inspection is difficult after assembly and quality control should include intermittent testing of joint strength from samples taken from the production line
- Almost invisible joint after assembly
- Control the surface energy of the surface to be fastened

7.2 Mechanical bonding

Design considerations that needs to be considered regarding mechanical bonding are presented below:

- Examination of stresses in the joint area under the fastener is important to determine the load-bearing capability and stiffness of the parts to be joined (Swift and Booker, 2013)
- Differentials in thermal expansion must be taken into consideration when using a fastener of different material to that of the base material (Swift and Booker, 2013)

- Minimize the number of fasteners for economic reasons
- Design for easy disassembly and maintenance of non-permanent fasteners
- Try not to place fasteners too close to edges or to each other because of assembly difficulty and reduced strength capacity
- Stress concentrations in fastener and joint designs should be minimised by incorporating radii, gradual section changes and recesses

Quality considerations regarding mechanical joining are presented as follows:

- Variations in tolerances can result in mismatched parts and cause high assembly stresses
- Variations in flatness of abutment faces can affect joint rigidity, corrosion resistance and sealing (Swift and Booker, 2013)
- Stress relaxation can cause the joint to loosen up over time
- Holes can act as stress concentrations and may cause corrosion
- Manufacturing tolerances are a function of the accuracy of the component parts and the fastening system used (Swift and Booker, 2013)

References

3M. Automotive homepage, 2016. URL http://www.3msverige.se/3M/sv_SE/automotive-ndc/. Last visited 2017-01-28.

3M. Automotive division presentation. 2017.

A2MAC1, 2017. URL https://www.a2mac1.com/home/loginpage/. Last visited 2017-02-28.

Lars Ahlstrand. Tesa interview. *Tesa*, 2017.

Arbetsmiljöverket. Manual for key indicator method manual handling operations (kim iii). *Bundesanstalt für Arbeitsschutz und Arbeitsmedizin*, 2012.

C. Berlin and C. Adams. *Production Ergonomics-Designing Work Systems to Support Optimal Human Performance*. Chalmers University of Technology, 2015.

G. Boothroyd, P. Dewhurst, and W. Knight. Product design for manufacture and assembly. *Second Edition*, 2001.

A. Bryman and E. Bell. *Business research methods*. Oxford University Press, 2015.

Statistiska Centralbyrån. Fordonstatistik, 2015. URL http://www.scb.se/hitta-statistik/statistik-efter-amne/transporter-och-kommunikationer/vagtrafik/fordonsstatistik/Tabellerochdiagram. Last visited 2017-01-25.

CEVT. Homepage, 2016. URL http://www.cevt.se/. Last visited 2017-01-29.

Q. Chen, H. Guo, K. Avery, X. Su, and H. Kang. Fatigue performance and life estimation of automotive adhesive joints using a fracture mechanics approach. 2017.

Robin Cooper and Robert S Kaplan. Activity-based systems: Measuring the costs of resource usage. 1992.

F. M. de Wit and J.A. Poulis. Joining technologies for automotive components. 2012.

M. Denscombe. The good research guide: For small-scale social research projects. 2014.

B. Dhillon. Life cycle costing for engineers. 2012.

Forbes. 5 stunning facts about the chinese car market you need to know, 2015. URL `http://www.forbes.com/sites/tychodefeijter/2016/05/16/five-things-you-need-to-know-about-the-chinese-car-market/#98fb39f1e738`. Last visited 2017-01-24.

A. Freivalds and B. W. Niebel. *Niebel's Methods, Standards and Work Design*. New York: McGraw-Hill, twelfth edition edition, 2009.

Suat Genc, Robert W. Messier Jr., and Gary A. Gabriele. A systematic approach to integral snap-fit attachment design. 1998.

International MTM Directorate. Sequential activity – and methods analysis system description. 2004.

Corinne N Johnson. The benefits of pdca. 2002.

Sohag Kabir. An overview of fault tree analysis and its application in model based dependability analysis. 2017.

R. Kaplan and S. Anderson. Time-driven activity-based costing. *Nov2004, Vol. 82 Issue 11, p131-138*, 2004.

Heléne Karlsson. Swerea ivf interview. *Swerea*, 2017.

C. LeBacq, Y. Brechet, H.R. Shercliff, T. Jeggy, and L. Salvob. Selection of joining methods in mechanical design. 2001.

Jeffrey K. Liker and David Meier. *Toyota Way Fieldbook - A practical guide for implementing Toyota's 4P*. McGraw-Hill Professional, 2006.

Lynk. Homepage, 2016. URL `http://www.lynkco.com/en/car-ampersand`. Last visited 2017-01-29.

McKinsey. Disruptive trends that will transform the auto industry, 2016. URL `http://www.mckinsey.com/industries/high-tech/our-insights/disruptive-trends-that-will-transform-the-auto-industry`. Last visited 2017-01-29.

Robert W. Messler, Suat Genc, and Gary A. Gabriele. Integral attachment using snap-fit features: a key to assembly automation. part 1 - introduction to integral attachment using snap-fit features. *Assembly Automation, Vol. 17 Iss 2 pp. 143-155*, 1997.

Nordisk Produktivitet, 2017. URL `http://www.nordiskproduktivitet.com/`. Last visited 2017-02-28.

S. N. Samy and H. ElMaraghy. A model for measuring products assembly complexity. *International Journal of Computer Integrated Manufacturing, 23:11, 1015-1027, DOI: 10.1080/0951192X.2010.511652*, 2010.

R. S. Sodhi, M. Sonnenberg, and S. Das. Use of snap-fit fasteners in the multi-lifecycle design of products. 1999.

R.H Jr Sturges and M.I. Kilani. Towards an integrated design for an assembly evaluation and reasoning system. 1992.

Konstantinos Stylidis, Casper Wickman, and Rikard Söderberg. Defining perceived quality in the automotive industry: an engineering approach. 2015.

K. G. Swift and J. D. Booker. *Manufacturing Process Selection Handbook, Chapter 11, Joining Processes*. Elsevier Ltd, 2013.

Tesa. Homepage, 2016a. URL `http://www.tesa.com/about-tesa/`. Last visited 2017-01-27.

Tesa. Application guide, tesa® acx^{plus} for the automotive industry. *Tesa*, 2016b.

Tesa. Bonding power, tesa® acx^{plus} for the automotive attachment part mounting. *Tesa*, 2016c.

Mikael Torslund and Niklas Hansson. Itw interview. *ITW*, 2017.

Tuve Skadecenter Workshop. Study visit. 2017.

WFP Office Of Evaluation. Evaluation matrix, 2017. URL `http://documents.wfp.org/stellent/groups/public/documents/reports/wfp263431~2.pdf`. Last visited 2017-03-05.

Kjell B. Zandin. *Maynard's Industrial Engineering Handbook, COST ACCOUNTING AND ACTIVITY-BASED COSTING, Chapter*. McGraw-Hill Professional, AccessEngineering, 2001.

A

Interviews

A.1 Lars Ahlstrand, Tesa AB

January 23, 2017

Tesa AB is one of world's leading manufacturer of technical adhesive tapes and self-adhesive system solutions, and works towards several industries with automotive as one of them Tesa (2016a). Lars Ahlstrand works as strategic segment manager in the Nordic automotive industry for Tesa, with several years of experience in adhesive taping.

A.1.1 Tape characteristics

Lars explains that tape consist of two main parts; a carrier and an adhesive substance. The carrier can be made of polyester, some kind of weave, or a gas (non-woven). The adhesive substance can be either a pure acrylic or a modified, depending on desired tackiness.

A common variant of tape is a so-called *filmic* tape, which is normally used in the electronics industry. The tape thickness can go down to $10\mu m$ and it is best suited for solid materials in small products.

For the automotive industry, *foam* tapes are a common option, due to its thickness and ability to absorb shocks. The foam can either be made of a *plastic*, usually polyethylene (PE), or an *acrylic*. The acrylic foam tape is elastic and more adaptable to material stress than the plastic foam, since it does not have a carrier.

Several layers can be added to a tape to achieve a set of specific characteristics and is usually the case when two different materials are to be joined together. Polyethylene (PE) and polypropylene (PP) are two common plastics used in the automotive industry. PE and PP has low surface energy which rejects the adhesive to stick.

In these cases, the surface energy has to be increased by either applying a primer, electrically charge it or blaze the surface with a gas.

Generally when discussing tape characteristics, Lars explains that there is usually a trade-off between three tape parameters; tackiness, adhesion and cohesion, presented as a trade-off triangle in Figure A.1. For example, the more tackiness and adhesion, the less cohesion. So for exmaple, an external plastic extension may need a harder (less tacky) adhesive in order to manage shear stresses, says Lars.

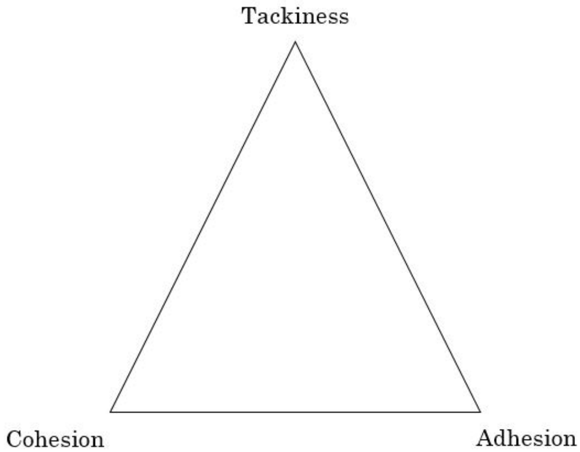

Figure A.1: Tape characteristics trade-off triangle

A.1.2 Application requirements

First of all, grease and dirt must be removed from the surface in order to apply the tape, says Lars. Second, the tape and the application surface must be within a certain temperature span of 15-35 degrees Celsius. If the temperature is too low, the wetting of the adhesive will not be complete. This can be adjusted be applying more pressure under a longer period of time or by storing the tape under the specified temperature span. This can be solved by using a hot cabinet or an IR plate for instance.

If the application surface is uneven or geometrical deviated in another way, a thicker tape with a softer adhesive is recommended according to Lars. Generally, it is harder to join two pieces with tape if they are not geometrically equal. "The tolerance requirements are narrower and different stress in the different materials can cause trouble when joining two parts with tape", Lars says.

A.1.3 Tools and aids

Several solutions are available to ensure the right placement of a part. For example, fixtures with compressed air can be used to both ensure placement with correct applied pressure, says Lars. Tesa head quarters in Hamburg develops, not only adhesive tapes but, tools (roller) to ensure correct application pressure of the tape by using poka yoke methods. Lars also states that the usage of automated robotic solutions is a common way of solving the issue of part placement, especially at pre-assembly by suppliers.

A.1.4 Service and wear

The possibility to disassemble a part is definitely harder when taped together, says Lars. First, a thin thread, a piano wire for instance, is needed to separate the joined parts from each other. Second, the left-over adhesive on the two surfaces must be removed with chemicals. This leads to a complex after market, with a lot a manual work.

Wear from water and dirt can vary depending on adhesive. Acrylic foam tape is resistant to water and wet, and withstands therefore high quality during the car's life span.

In cold temperatures below -10 degrees Celsius, the adhesive freezes and the foam absorbs all shocks instead.

A.1.5 Advantages and disadvantages

The primary advantage with tape is that it requires no hole stamping in the car body. Holes in the car body is always a source for corrosion, says Lars. The tape has also excellent adherence characteristics along with a more even load on the part design. As a bonus, the tape will also function as an automatic sealing, that in a mechanical binder case would have been necessary to apply afterwards anyhow, according Lars.

The greatest weakness of tape is its ability to carry parts. If the part is too heavy, some kind of mechanical binder is needed to compensate. Another weakness is the need of surface treatment of PP/PE plastics in order for the tape to wet out.

A.1.6 Summary

Adhesive taping is a great solution to fasten two different material to each other. It is a method with great potential, and Lars is excited about the future. However, his experience in automotive industry is that exterior body extensions are fastened with tape in combination with mechanical fasteners. This is to enable a quality assured fastening of heavier body parts.

The tape's ability to conduct electricity and heat is also improving and can be of importance for future applications.

Cost is also an important factor when deciding on what fastening method to use. With long experience in the automotive industry, Lars is estimating that the cost of adhesive taping is similar to a mechanical attachment of body parts.

A.2 Uno Andersson, 3M

January 26, 2017

With more than 100 years of experience in automotive industry, 3M is a global leading manufacturer of innovative products and services 3M (2016). Uno Andersson works as a Senior Sales Executive for the Nordic Automotive Division for 3M, with over 27 years of experience in this specific area.

A.2.1 Acrylic foam tapes

3M has been developing acrylic foam tape since 1979, says Uno. The acrylic foam tape is a common joining product for exterior body side moldings in the automotive industry.

Parameters that must be taken into consideration when applying a tape is temperature, pressure and time. All parameters must be applied within its own interval, thus e.g. more pressure cannot compensate for too low temperature. Also, the width of the tape is crucial. No tapes below 5mm in width are manufactured due to poor wet-out and joining features, according to Uno.

A.2.2 Applications

The acrylic foam tape can be used for numerous of different applications, where exterior body parts are one of them. An exterior body part must be able to withstand several external exposures, such as initial and residual stress, cold shock absorption, weather resistance, defined holding force, coefficient of thermal expansion, and vibration and shear loading.

A.2.3 Quality assurance

To make sure the tape is applied correct according to the application parameters, car manufacturers commonly automates this process. Steering pins are used to fit the part into position and an automated wheel are used to apply the wetting with correct pressure during the right time. Cleaning of the surface before application can be done by hand or automatically.

The combination of adhesive taping and mechanical joining is common when there are two different application planes on the part. Figure A.2 represents a part design mounted on two different application planes, which puts high requirement on the method if tape is to be used on both planes.

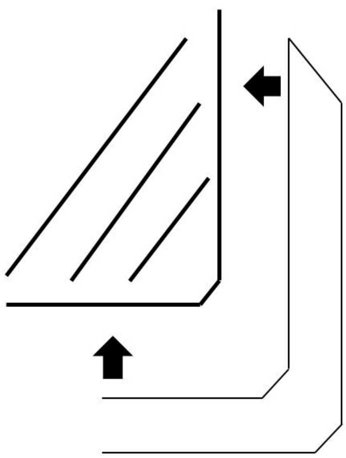

Figure A.2: Visualisation of two different tape planes

The issue with fitting two tape planes at the same time and at the exact same position, is one reason why one of the planes is joined with a mechanical solution instead. A common situation is to use mechanical fasteners on the lower segment and adhesive tape on the upper, according to Uno's experience in automotive industry.

The critical precondition for joining two parts with adhesive tape is that the two application surfaces are parallel. If not, the wetting cannot be guaranteed and the quality of the joint is insignificant. The surface fitting is tested before the production is active to enable room for adjustments of the process. It is usually the process or material tolerances that are creating quality issues, not the actual tape, says Uno.

A.2.4 Summary

With almost 30 years of experience in the automotive industry, Uno Andersson has great knowledge in tape solutions for car manufacturing and he says that the trend has been very much stable during the past 10 years, however the usage of tape can vary depending on design trends. Nevertheless, our products have been developed according to the demands on the market and will continue to improve in the future, says Uno.

Although taping is a relatively sensitive technique, the end result can be very effective. As long as you have a stable process with the right tolerances, working in the defined temperature span, you can achieve a joining solution with reduced noise and weight, sealed, resistant with continuous loads, and without the risk of corrosion.

A.3 Marcus Jonasson, VCC

January 31, 2017

Marcus Jonasson works for Manufacturing Engineering in the Exterior department at VCC. Marcus has knowledge and experience in different application techniques for exterior details of the car.

A.3.1 Today's situation

The use of adhesive tapes and snap-fit fasteners are varying in the automotive industry, depending on manufacturer and demands. We are manufacturing cars where the combination of adhesive tapes and snap-fit fasteners usually is the case for exterior mounting, says Marcus. There has been some minor quality problems with these solutions for some models, and the tape is usually blamed. However, I believe it is the snap-fit fasteners that is the problem in this case, claims Marcus. The geometrical variance of the holes leads to tension build-up in the material when the snap-fit fasteners are attached, which rules out the wetting quality of the tape.

A.3.2 Tape project

There has been a thorough investigation performed here at VCC where the use of adhesive taping for exterior parts, mainly the fender flare, were analyzed, says Marcus. The main objective was to see if exterior parts could be attached without creating new variants of the car model, such as new holes on the body. Other car manufacturer's, such as Audi, Skoda, and Mercedes Benz, exterior mounting solutions were analyzed and the result was interesting, to say the least. Some car manufacturers have actually succeeded in joining exterior parts with solely adhesive tape, which enables them to reduce the number of variants in the production.

A.3.3 Positioning

The positioning of taped exterior parts can be solved with either fixtures or steering pins. The latter one requires making holes in the car body, which creates variants, that is a problem. However, innovative solutions are developed to solve this issue. The fender flare, for example, can be separated into three individual parts where one is connected to the front bumper and one to the rocker panel. Since holes are already made for these parts, the fender flare can be positioned using a fixture in combination with these reference points that are already manufactured, without creating any variance, says Marcus. This solution requires an early assembly of the fender flare in the production since the bumper and the rocker panel cannot be attached before. An early assembly also facilities a cleaner and improved wetting surface due its connection to the painting station.

A.3.4 The detail

A detail that are to be attached with snap-fit fasteners must contain extra internal bars, in order to make room for the snap-fit. More material will therefore be added, and design restrictions will arise. If the detail could be taped instead, we could save a lot of material and design with more freedom, says Marcus.

A.3.5 Serviceability

The serviceability is an important aspect in terms of repairing damaged parts without breaking any adjoining details. A common case in the after market is to replace a damaged bumper. Marcus explains that, if the fender flare is in one piece and solely attached with adhesive tape, it must be removed before the bumper, for instance. Removing a part that is taped is not easy and when complete, the removed part is scrap and adhesive residues must be removed from the body. This can be solved by either separating the part into individual pieces, as explained earlier, or the attachment can be divided into different sections where different joining techniques can be used. For example, the part of the fender flare that is adjoined with the bumper can be attached with snap-fit fasteners, while the remaining section is taped. This enables a possible disassemble of the bumper with just removing the snap-fitted part of the fender flare, while the taped part remains intact. When the new bumper is attached, the snap-fits are just connected to its joining holes.

A.3.6 Summary

We have developed and tried fixtures for a whole tape mounting solution, says Marcus. The biggest problem, from a production assembly perspective, is however the level of operator dependency required for the operation. This puts more requirement and responsibility on the operator, which both can be negative and positive. Of course, the high repetitiveness is crucial and fool-proof (poka-yoke) solutions are always preferable. But in order to manufacture high quality cars, there is also a need for the human instinct and adjustments, Marcus says. If we always strive towards snap-fit solutions, there will be no room for innovative solutions in the future. We have trained operators that, I believe, has the driving force to make high quality cars and there is no reason why we should not trust their capability, says Marcus.

Nevertheless, for future development of adhesive taping solution, there is a need of gaining more geometry control over the application areas at the car body. As for now, we do not have enough control over the geometry of the car body and the part to be assembled, which leads to high tension areas that cannot be attached with adhesive tapes, says Marcus. Yes, the prerequisites for adhesive taping are greater than snap-fit fasteners. But if these can be achieved, we are on a good path of creating even more innovative solutions for our cars.

A.4 Heléne Karlsson, Swerea IVF

February 1, 2017

Heléne Karlsson works with Adhesive Bonding at the Multimaterial Design Group at Swerea IVF. Heléne has over 30 years of experience in joining and adhesive bonding techniques.

A.4.1 Innovative solutions

The most common issue with adhesive tapes is once it is mounted, you can not remove it without breaking it. Once removed, it usually damage the bonded surface and result in scrapping the attach part, due to the strong adhesion. To solve this, innovative research is done in this field, says Heléne. For instance, we are currently looking into solutions where the adhesive can be released and debonded ”on demand” by exposure to electricity, temperature or chemicals etc. The adhesive can then easily be removed without leaving residuals on the bonded surface, Heléne tells. There is also solutions, mainly within the medical industry, where the adhesive is released when exposed to visible light. Another interesting solution for future car manufacturing industry is the so called Gecko tape. Scientists are here working to imitate and make syntetic materials that use gecko-like nanostructures for adhesion like the Gecko lizards. The Gecko tape has no adhesive but attaches to the surface through van-der-Waal forces, which enables it to be removed and re-attached on demand, says Heléne. The Gecko tape is currently very expensive and therefore unfortunately not relevant to industry at this point.

A.4.2 Technical aspects

Within the acrylic foam tape family, for pressure-sensitive adhesives (PSA), there are mainly three groups of tapes; one group of tapes with a backing material and two groups of foam tapes without backing material defined by 3M; VHB (Very High Bond) and SBT (Structural Bonding Tape). VHB is a non-hardening tape built up with only one layer of acrylic foam and is a tape used in for example car manufacturing industry. VHB has a shear strength of 1 MPa, which is approximately equal to 10 kg=cm2. The SBT tape consists of epoxy fluid adhesive that is embedded in small ”spheres” and added into the acrylic matrix foam tape. The shell of the spheres breaks during the heat-curing. The epoxi adhesive then flows out and cures, which hardens the tape. When hardened, the SBT has a shear strength of appr.10 MPa (100 kg=cm2). In this way the VHB tape combines the high bond strength of thermoset curing epoxy with the convenience of VHB tape.

One important aspect for high volume manufacturing is to have immediate adhesion with high tackiness, to avoid stoppage of the production line. This is achieved with the acrylic foam tape due to its initial wettability and tackiness. The adhesive bond strength is strongly dependent on the surface free energy and wettability of the materials surface. The higher the surface energy the better adhesive tape bonding and joint strength. A adhesive bonded joint is best designed for shear forces and the opposite for peel forces, which should be avoided. Stiffer and stronger adhesives that usually are less ductile will develop stress concentrations at the end of the joint. Joints that make use of stiff adhesives and with high shear strength plus temperature resistance are therefore often very sensitive to peel forces. Due to this should not harder adhesives be selected than necessary, says Heléne.

A.4.3 Tape testing

The tape's ability to bond and join two parts are tested by separating them from one and other. When doing this, we are looking for failure strength and also the mode of failure. The failure mode could be either adhesive or cohesive failure, where we prefer cohesive failure in the substrates/adhesive or tape. Adhesive failure in the surface should be avoided. The surface quality and the strength and mode of failure of the bonded joint could be an indication of the surface cleanliness, says Heléne. Adhesive failure mode indicates that the adhesive joint is not strong enough and that the surface treatment do not fulfilled the pre-conditions as desired. A cohesive failure, on the other hand, usually indicates a very good adhesion.

A.4.4 Summary

The primary risk with using adhesive tapes in industry is to ensure the quality via the adhesion and wetting, says Heléne. The combination of the adhesive/tape and the substrates needs to be compatible. The quality of the finished bonded joint is also difficult to secure without destructive testing. However, there is one tape that changes its color after curing. When curing has taken place does the SBT-tape change its color, from originally black to grey. This can be used as a confirmation of that an accurate curing has taken place for achieved quality.

A common problem today is that the adhesive process not is originally designed for adhesive and tape bonding and instead is used as an emergency solution. Often is the joint design prepared for another joining method as welding or mechanical joining. It is therefore of great importance that tape bonding could be involved earlier in the development phase, so that the tape bonding method would be utilized to its fully potential. Due to that the bonded joint is continuous, an overall increase in body stiffness is achieved. Tape bonded joints are therefore very good with handling vibrations and has much better fatigue strength than mechanical fasteners, which is beneficial in the car manufacturing industry, says Heléne. The usage of tapes are increasing, especially due to use of new materials and combination of different materials in the same constructions. The trend is also going towards adhesives that are a combination of different adhesive groups. VHB tape is a good example of this were a tape and a epoxy thermoset curing fluid adhesive are combined into one product. Combination of hot melt adhesives and thermoset curing adhesives is another example. Also new curing methods and adhesives/tapes that hardens at lower temperatures are now introduced. There are between 40-90 000 different materials available. To join these different materials there are though only three processes. These three methods are mechanical attachment, welding and adhesive bonding. The possibility to join dissimilar materials is here one of the most important advantages for adhesive bonding, so we have to be open for innovative solutions in the future!

A.5 Johan Jacobsson, Din Bil

February 15, 2017

Jonas Jacobsson tells us that he has no experience at all of taped or snap-fit fastened plastic extensions loosening its grip without any external impact and solely because of wear. It has to be some kind of damage caused by an external impact for a plastic extension to loosen its grip, says Jonas. He has also no experience of corrosion on the chassis or in the holes used by snap-fit fasteners.

Substituting a snap-fit fastened extension is relatively easy to do with manual force. The extension remains intact and broken snap-fit fasteners is easy to swap to new ones. On the contrary, it is much harder to substitute a taped extension than a snap-fit fastened extension. The procedure of substituting a snap-fit fastened extension often results in some sort of damage on the extension which leads to the need of a new one. This results in higher costs and more time demanding processes. Sometimes, the plastic extension require a certain paint so the workshop also need to paint the extension before assembling it since it is not possible to keep all color variants in stock. The working procedure for changing a taped plastic extension is as follows:

1. Apply heat to the plastic extension to increase the flexibility of the adhesive tape
2. Apply manual force to peel off the plastic extension from the car body
3. Polish the chassis surface for removal of adhesive residues
4. Clean and dry the surface
5. Bring forward a new plastic extension and position it
6. Manually apply pressure with hands for a intuitive amount of time

A.6 Anders Bergman, Plastal

February 22, 2017

Anders Bergman works as a Team Leader for the Exterior department at Plastal. Plastal works close to their customers, early in the development phase. This enables us to have a better control of the process and contribute with valuable input, says Anders.

A.6.1 Analyze

The softer the plastic detail is, the better tape wetting. Stiff plastic detail cannot follow the attachment surface as good, which will result in higher stresses if tolerances are not matching and worse tape characteristics, says Anders. And a detail with adhesive tape requires a good follow between the part and the surface.

Adhesive tape is an expensive solution to implement in the late development phases, without designing for it. The relative cost for the different attachment methods are:

1. Integrated snap-fit
2. Snap-fit fastener
3. Adhesive tape

A.6.2 Process break-down

For the pre-assembly of a fender flare with both snap-fit and adhesive tape as fasteners, the following processes are included, where the order of operation 2-6 can vary:

1. Injection moulding
2. Ultrasound welding
3. Flaming
4. Tape assembly
5. Snap-fit fastener assembly
6. Finger lift

Anders mentions that snap-fit fasteners with pre-assembled sealing are expensive compared to regular snap-fit fasteners. Also, the finger lift added to the tape liner requires an extra process step, which is of course a cost.

A.6.3 Testing and design

Plastal is responsible for the component testing and Volvo is responsible for the whole car test.

Anders mentions that there is always a trade-off between geometry design and assembly, it is common that the part is difficult to assemble because of too complex geometry design.

A flexible design is necessary for a tape solution. If a more vigorous design of the fender and the fender flare is desired, snap-fit fasteners are preferable, depending on the fender flare stiffness.

The fender flare design is usually divided into two parts; a carrier and a shelf. By using a carrier, a robust design is achieved where reference pins also can be integrated. Additionally, the fender flare can be held in the carrier when going through painting.

A.6.4 Designs

- 100% fender flare - Not 100% fender flare
- Narrow - Wide
- Paint - No paint
- Carrier - No carrier

A.6.5 Cost

As a rough estimation, one can say that 1 meter of adhesive tape corresponds to 10 pieces of snap-fits in purchase price, where mounting tools and assembly time must be added to it. This is derived from a 6mm wide tape and snap-fit fasteners without sealing function.

Overall, there is no best practise available and choice of process cannot be generalized since all aspects of the construction must be taken into consideration.

A.7 Mikael Torslund & Niklas Hansson, ITW

Mars 6, 2017

Mikael works as Global Key Account Manager and Niklas as Project Manager mainly towards Volvo Cars for ITW Sweden. Mikael and Niklas has extensive knowledge and years of experience in snap-fit fastener technology for car manufacturing. If I must choose one, I believe that the hybrid solution where snap-fit fasteners are complemented with adhesive tape is the very best solution from a quality perspective, says Mikael.

A.7.1 Snap-fit technology

Although almost every snap-fit fastener is customized for its purpose and application, there are some categories that the snap-fit fasteners are divided into.

Four legged
The four legged snap-fit is a traditional fastener with good characteristics, however requires complete perpendicular mounting to avoid breaking. The four legged snap-fit fastener is visualized in Figure A.3.

Figure A.3: The four legged snap-fit fastener

Heart flex
The heart flex snap-fit, see Figure A.4, is an ITW patented solution and was developed to allow not complete perpendicular mounting without breakage. However, the construction makes it more stable along the x axis compared to the y axis.

Figure A.4: The heart flex snap-fit fastener

Triple heart flex
The triple heart flex, see Figure A.5, is an evolution from the regular heart flex with more stable characteristics from a mechanical strength perspective. Three legs allows the snap-fit to be equally stable along the mounting plane.

Christmas tree
I would not like to call the Christmas tree snap-fit a traditional snap-fit fastener since you do not get the verification of the "feeling" of complete mounting, says Mikael.

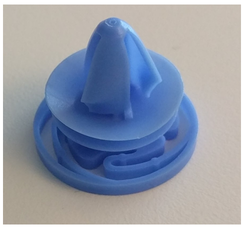

Figure A.5: The triple heart flex snap-fit fastener

The step-wise construction allows the snap-fit to be used over different geometries, but will not achieve the same level of quality as a regular snap-fit, Niklas tells. The Christmas tree snap-fit fastener is presented in Figure A.6.

Figure A.6: The Christmas tree snap-fit fastener

A.7.2 Common issues

The most common problem is when our customers does not involve us early enough in their development phase, says Mikael. Our expertise and experience is necessary to achieve excellent result, since it is a very delicate process working with snap-fit fasteners, Niklas says. One tenth of a millimeter can be the difference between success and disaster. Using snap-fit fasteners puts high requirement on geometry which leads to a lot of work with trim and tolerances.

The play between surface and the part is hard to control with using solely snap-fit as fasteners, which is why the combination with adhesive tape can be a good solution. The play between surface and the part is usually solved by shorten the distance of the snap-fit, however this is a very delicate process since every tenth of millimeter is critical. The first version of the Volvo XC90 had this issue, the snap-fit fasteners were designed too short so the actual part reached the bottom before the snap-fit. The design then had the be fine tuned and trimmed by us until perfection were reached.

A.7.3 Ergonomics

A myth is that the mounting of snap-fit fasteners is verified by a snap sound. However, the plastic parts usually works as a sound isolator and the size of the parts usually makes it hard to distinguish any sound when mounting. It is rather a snap "feeling" that appears and that the operator has to learn to recognize when mounted correctly, says Mikael.

When measuring the mounting force needed, common equipment indicates when the mounting reaches the bottom, which is miss leading. The mounting force is the force required to mount the part, which is just before the bottoming peak. This is why the given mounting force often is wrong in assembly, and ergonomics can be considered differently.

A.7.4 Design

Some design and assembly aspects were brought up on the meeting:

- A regular snap-fit fastener is designed to be disassembled up to 5-10 times.
- The higher strength requirement on the snap-fit fastener, the higher assembly force
- The relationship between assembly and dis-assembly force is a continuous trade-off
- It is hard to track a broken snap-fit when assembled
- Important to choose the right snap-fit for right function, so it does not break when assembled. There are snap-fits that are built to manage skewed assembly better than others
- Do not use regular snap-fit as steering pins since they are made to fit higher tolerances
- A painted surface has less friction compared to an unpainted one
- Every snap-fit is designed to withstand at least 100-150 N in pull-of force

A.7.5 Material and application surface

The snap-fit fasteners puts high requirements on the material. Polyamide, for instance, is highly sensitive to humidity and can become brittle if not the humidity is controlled correctly. It is therefore important to use a material that can maintain the right quality over time.

The hole to attach the snap-fit in is also important to consider. It is important that the mounting direction of the snap-fit is the same as the punching direction of the holes. Due to deformation of the material, the punching process creates a small neck at the end of the hole, which must be mounted onto the right direction, otherwise the snap-fit fastener will break.

A.7.6 Cost

The cost of snap-fit fasteners varies depending on production volume and design complexity and is set according to material and process time of manufacturing. However, one can say that the purchase price of a regular piece of snap-fit fastener is between 0.2-0.6 SEK. The snap-fit fasteners sometimes comes with a sealing function, which can be manually assembled to the snap-fit or integrated in the injection moulding process. The sealed snap-fit is therefore more expensive compared to the regular snap-fit, where the manual assembled sealing is the more expensive one with a purchase price over 1 SEK.

A.7.7 Summary

Overall, we have good quality experience in the use of snap-fit fasteners, says Mikael. The plastic material relaxes over time, and can be the one reason for noise and vibrations of the joint. However, the plastic never relaxes down to zero.

The actual assembly is the critical moment for the snap-fits and is the state we design towards. In this, the relationship between assembly and dis-assembly force is probably the area we spend most of our time, says Niklas. There is a constant trade-off between these two, and due to its contradictory characteristics, it is often hard to please all needs.

To sum up, Mikael and Niklas believes that the three success factors of snap-fit fasteners are:

- Fast assembly
- Low purchase price

- Independent on the operator

A.8 Johan Håkansson, VCC

Mars 15, 2017

Johan works as PSS owner at the R&D department at Volvo Cars with many years of experience regarding quality issues and technical requirements of part designs and its attachment techniques.

A.8.1 General prerequisites

The prerequisites for adhesive tape and snap-fit fasteners are important to meet, otherwise there is a risk that the process will fail. Generally, the backbone of the adhesive tape process is to achieve:

- Clean application surface
- Geometrically secured
- Right temperature and humidity span
- Full wetting

It is extremely important the requirements are fulfilled and that the process is working. If one of the requirements above is missing, the process cannot be quality assured, says Johan.

The process for snap-fit fasteners is not as sensitive but must meet the prerequisites:

- Right temperature and humidity span
- Geometrically secured

A.8.2 Common issues

The most common problem for us during the construction and manufacturing phase is to understand the geometrical deviations of a designed part and the outcome of the real part, Johan tells.

A.8.3 Design and manufacturing engineering

The decision making process of what attachment technique to use is governed by the desired design and environmental parameters. Early simulations enables recommendations for the process but the decision is rarely decided solely on cost, says Johan.

From a production planning perspective, parts attached with adhesive tape should be placed as early as possible in the assembly line. Early in the assembly line means that the cleanliness of the surface and the surface energy is optimal for full wetting of the tape. Of course, this is not always possible due to some required assembly sequences which usually results in a trade-off.

Shear loads and elongation caused by thermal loads of the part can be a reason why adhesive tape is not enough as fastener when the moment of inertia is high, says Johan. For more slim design, which equals low moment of inertia in the cross section, adhesive tape is an efficient attachment technique.

A.8.4 Primer

Primer is a chemical mix that can be used to enable better, early wetting of the tape. However, due to volatile hydrocarbons which is poisonous the mix should not be used in production assembly, says Johan. Environmental legal requirements can change quickly, especially in countries like China. Therefore, we are not using primer nor relying our process on it either, claims Johan.

A.8.5 After market feedback

The data from after market feedback comes directly from our workshops around the world and is category-based, says Johan. This means that the level of detail can vary from the reports, which makes it hard to track. A lot of effort must be put in to analyze the data, and there are no guarantees to succeed finding what we are looking for, says Johan.

Complaints from customers are supposed to be handled by our component and car verification we perform, says Johan. Also, the correlation between testing and real production is important to understand. There are cases where the same equipment is not used in testing as in the real production, and this is important to consider when developing and understanding new processes.

We can see a need for better work routines regarding the feedback system, since it is an efficient way of improve ourselves and our products, says Johan.

A.8.6 Summary

Regarding cost, tape is less expensive when it comes to solely purchase price. However, a slimmer design can be achieved when using adhesive tape as attachment technique which leads to a less complex part. The main conclusions from our experience is that parts expected to be replaced or changed frequently should preferably not be attached with adhesive tape, Johan says.

B

Study visits

B.1 Tuve skadecenter workshop

Tuve skadecenter performs reparations on Volvo cars which includes repairing or substituting plastic exterior body parts. The purpose of the study visit was to do observations and discuss with an experienced mechanic about the serviceability of exterior plastic parts depending on if adhesive tape or snap-fit fasteners are used.

B.1.1 Common issues

The mechanic tells us that the plastic part in itself often remains intact throughout the car's life-cycle. Paint damages are a common reason for part replacement, and when a paint damage occur it is necessary to remove the exterior plastic parts located close to the paint-damaged spot to be able to repaint the damaged surface properly without risking any paint on the plastic extensions. Another common reason for removing the fender flare is when a front or back bumper needs to be repaired or substituted.

It is very rare that snap-fit fastened or taped plastic extensions looses its grip in itself. However, sometimes taped plastic extensions loose their grip due to tensions or external damage and needs to be fixed, which also lead to removal of the plastic extension. Taped extensions are also weak against peeling and sometimes looses their grip in one corner which later lead to further loosening due to wear and damp.

Snap-fit fastened extensions occasionally shows small gaps on the edges when no adhesive tape is being used that could lead to water sipping through the plastic extension from top to bottom. This is usually not a problem more than the aesthetically since the mechanic says that he never experienced any corrosion in the holes used for snap-fit fasteners. The fender flares on a Volvo XC70 model uses a hybrid solution with both snap-fit fasteners and adhesive tape. This solution has had problems with snap-fit fasteners creating a tension that led to loosening of the adhesive tape in some areas. This issue was fixed when some of the snap-fit fasteners were removed (See picture).

B.1.2 Serviceability

When a mechanic performs a reparation or substitution of a plastic extension it is always removed from the car body. Removing a snap-fit fastened extension is fairly easy, you just have to pull it off by force and it usually stays intact, which makes it possible to reuse the extension. New snap-fit fasteners may be necessary if the old ones breaks during this process. A taped extension on the other hand, is fairly difficult to remove from the car body. You have to use more force to pull it off compared to a snap-fit fastened extension, or you could make it easier by heating the extension so the adhesive tape gets more flexible and looses its grip. As a result, an extension could possibly be damaged due to the high force required to pull it off and thus in need of replacement even though it was not damaged from before.

Another issue with taped extensions is that the adhesives is very difficult to remove from the extension and car body. A polisher with a rubber surface can be used to grind the adhesives of the chassis but it is not possible to use the same method on the plastic extensions since its edges usually gets damaged in this process. With this in mind, it is very hard to remove adhesives from the plastic extension and it is usually not worth the effort. Instead, when a taped extension is removed from the car body, the mechanic always change it for a new one.

It is also difficult to fasten the extension in the repair-shop with adhesive tape, probably partly due to an inadequate working technique. The mechanic tells us that the extension is fastened for a while but after a few weeks, when being exposed for the outside environment, it usually looses grip. One reason for this is because the pressure is applied manually by hand with intuition and without any insurance of the wetting quality. The time of the pressure and the cleaning of the surface is also done manually with intuition. Volvo provides the repair-shops with necessary instructions of how to correctly attach the plastic extension with adhesive tape, but in practice it is seldom used. As a consequence of this and frequent substitutions of extensions, the scrap rate of taped plastic extensions increases. Moreover, a high scrap rate leads to high costs for the insurance company or the customer, says the mechanic.

B.1.3 Workshop case

Tuve skadecenter workshop received a Volvo XC70 with a damaged paint on one of the doors requiring repainting. To achieve exactly the same color tone, both doors had to be repainted. To do this, the two lower door molders and the rocker panel had to be removed from the car body. The rocker panel were fastened with snap-fit fasteners so it could easily be disassembled and reused when the painting job was done. Contrary to this, the lower door molders were both taped on the upper edges so it was not possible to remove the adhesive tape completely from the old fender flares. The remaining residues on both door molders required them to be substituted into new ones even though both were intact.

Summarized, a paint job on a door resulted in the substitution of door molders in addition to the initial paint job.

C

MTM-SAM

The MTM-SAM studies are presented below in Figure C.1, C.2 and C.3.

SAM Analysis Form

Object	WAE	Date 4/3/2017	Reg.nr
Operation	Clips	Issued by Anton Filip	DWG No.
			Page of

Method description	GET Step S	GET GS 80	GET GS 45	GET GS 10	GET Add. for Handful -H	PUT Weight >5 kg AW	PUT Step S	PUT PD 80	PUT PD 45	PUT PD 10	PUT Add. for Precision -P	PUT Apply Force AF	USE No.of strokes, grips etc.. f	USE No.of places n	USE Time of stroke,prip etc t	USE =	USE Apply Force AF	RETURN PUT Weight > 5 kg AW	RETURN PUT Step S	RETURN PUT PD 80	RETURN PUT PD 45	RETURN PUT PD 10	RETURN PUT Add. for Precision -P	RETURN PUT Apply Force AF	RETURN PUT Bend+Arise B	Summing up Factors F	Summing up Factors f	Summing up Total
	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	3	2	3	5	4	2	3	3	12	F	f	Total
Snap-fits	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Get part from material rack		1																								5	1	5
	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Position part on to fender with the guidance from the snap-fits								1		8	9															48	1	48
	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Apply the part on to the fender by applying pressure to all snap-fit spots				13								14														68	1	68
Final attach with screw fastener	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Get tool and two screws		1	1																							9	1	9
	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Apply the two screws in to the holes									2		2						2									20	1	20
	3	5	4	2	6	2	3	5	4	2	3	3				MT	3	2	3	5	4	2	3	3	12			
Tighten screws and return tool													5	1	2	10				1						15	1	15

Calculation:		
	Total net time (factors)	165
	Total net time (TMU)	825
	Total net time (seconds)	29.7

Figure C.1: MTM-SAM Clips

SAM Analysis Form																												
Object: WAE	Date: 4/3/2017																		DWG No.									Reg.nr
Operation: Tape	Issued by: Anton Filip																		Page of									
Method description	GET					PUT							USE					RETURN PUT								Summing up Factors		
	Step	GS			Add. for Handful	Weight >5 kg	Step	PD			Add. for Precision	Apply Force	No.of strokes, grips etc..	No.of places	Time of stroke,prip etc		Apply Force	Weight > 5 kg	Step	PD			Add. for Precision	Apply Force	Bend+Arise			
	S	80	45	10	-H	AW	S	80	45	10	-P	AF					AF	AW	S	80	45	10	-P	AF	B			
	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	3	2	3	5	4	2	3	3	12	F	f	Total
Clean surface	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Get wiper from table		1																								5	1	5
	3	5	4	2	6	2	3	5	4	2	3	3				FA	3	2	3	5	4	2	3	3	12			
Get isopropanol from table and add it to the wiper. Return isopropanol			1						1				2	1	2	4					1					16	1	16
	3	5	4	2	6	2	3	5	4	2	3	3				FA	3	2	3	5	4	2	3	3	12			
Apply wiper on surface		1											3	1	7	21				1						31	1	31
Dry surface	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Take dry wiper from table		1																								5	1	5
	3	5	4	2	6	2	3	5	4	2	3	3				FA	3	2	3	5	4	2	3	3	12			
Apply dry wiper on surface and return									1				3	1	7	21				1						30	1	30
Positioning (fixture)	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Get fixture from rack		1		1																						7	1	7
	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Position fixture to fender									1	1	2						2									18	1	18
	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Get part from rack and place in fixture		1	1						1	1	2						2									27	1	27
Liner removal	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Grab finger lift and pull liner. Throw away waste liner		1						1									1			1						18	1	18
Pressing	3	5	4	2	6	2	3	5	4	2	3	3				FA	3	2	3	5	4	2	3	3	12			
Get tool from rack and fix the part by stroking back and forth with pressure. Return tool		1							1				6	1	7	42				1						56	1	56
	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Get fixture and remove from fender		1		1													1			1						15	1	15
Final attach with screw fastener	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Get tool and two screws		1	1																							9	1	9
	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Apply the two screws in to the holes									2		2															14	1	14
	3	5	4	2	6	2	3	5	4	2	3	3				MT	3	2	3	5	4	2	3	3	12			
Tighten the screws and return tool													5	1	2	10				1						15	1	15
Calculation:																				Total net time (factors)								245
																				Total net time (TMU)								1225
																				Total net time (seconds)								44.1

Figure C.2: MTM-SAM Tape

SAM Analysis Form																												
Object: WAE	Date: 4/3/2017																										Reg.nr	DWG No.
Operation: Hybrid	Issued by: Anton Filip																										Page of	
	GET					PUT							USE					RETURN PUT								Summing up Factors		
	Step	GS			Add. for Handful	Weight >5 kg	Step	PD			Add. for Precision	Apply Force	No.of strokes, grips etc..	No.of places	Time of stroke,prip etc		Apply Force	Weight > 5 kg	Step	PD			Add. for Precision	Apply Force	Bend+Arise			
Method description	S	80	45	10	-H	AW	S	80	45	10	-P	AF					AF	AW	S	80	45	10	-P	AF	B			
	3	5	4	2	6	2	3	5	4	2	3	3	f	n	t	=	3	2	3	5	4	2	3	3	12	F	f	Total
Clean surface	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Get wiper from table		1																								5	1	5
	3	5	4	2	6	2	3	5	4	2	3	3				FA	3	2	3	5	4	2	3	3	12			
Get isopropanol from table and add it to the wiper. Return isopropanol			1						1				2	1	2	4					1					16	1	16
	3	5	4	2	6	2	3	5	4	2	3	3				FA	3	2	3	5	4	2	3	3	12			
Apply wiper on surface		1											3	1	7	21				1						31	1	31
Dry surface	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Take dry wiper from table		1																								5	1	5
	3	5	4	2	6	2	3	5	4	2	3	3				FA	3	2	3	5	4	2	3	3	12			
Apply dry wiper on surface and return									1				3	1	7	21				1						30	1	30
Positioning	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Position part on to fender with the guidance from snap-fits		1		1					1	1	2						1									22	1	22
Liner removal	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Grab finger lift and pull liner. Throw away waste liner		1						1									1			1						18	1	18
Pressing	3	5	4	2	6	2	3	5	4	2	3	3				FA	3	2	3	5	4	2	3	3	12			
Get tool from rack and fix the part by stroking back and forth with pressure. Return tool		1							1				3	1	7	21				1						35	1	35
Snap-fits	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Apply the part on to the fender by applying pressure to all snap-fit spots				13				1		8	9	14														116	1	116
Final attach with screw fastener	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Get tool and two screws		1	1																							9	1	9
	3	5	4	2	6	2	3	5	4	2	3	3					3	2	3	5	4	2	3	3	12			
Apply the two screws in to the holes									2		2															14	1	14
	3	5	4	2	6	2	3	5	4	2	3	3				MT	3	2	3	5	4	2	3	3	12			
Tighten screws and return tool													5	1	2	10				1						15	1	15
Calculation:																										Total net time (factors)		295
																										Total net time (TMU)		1475
																										Total net time (seconds)		53.1

Figure C.3: MTM-SAM Hybrid