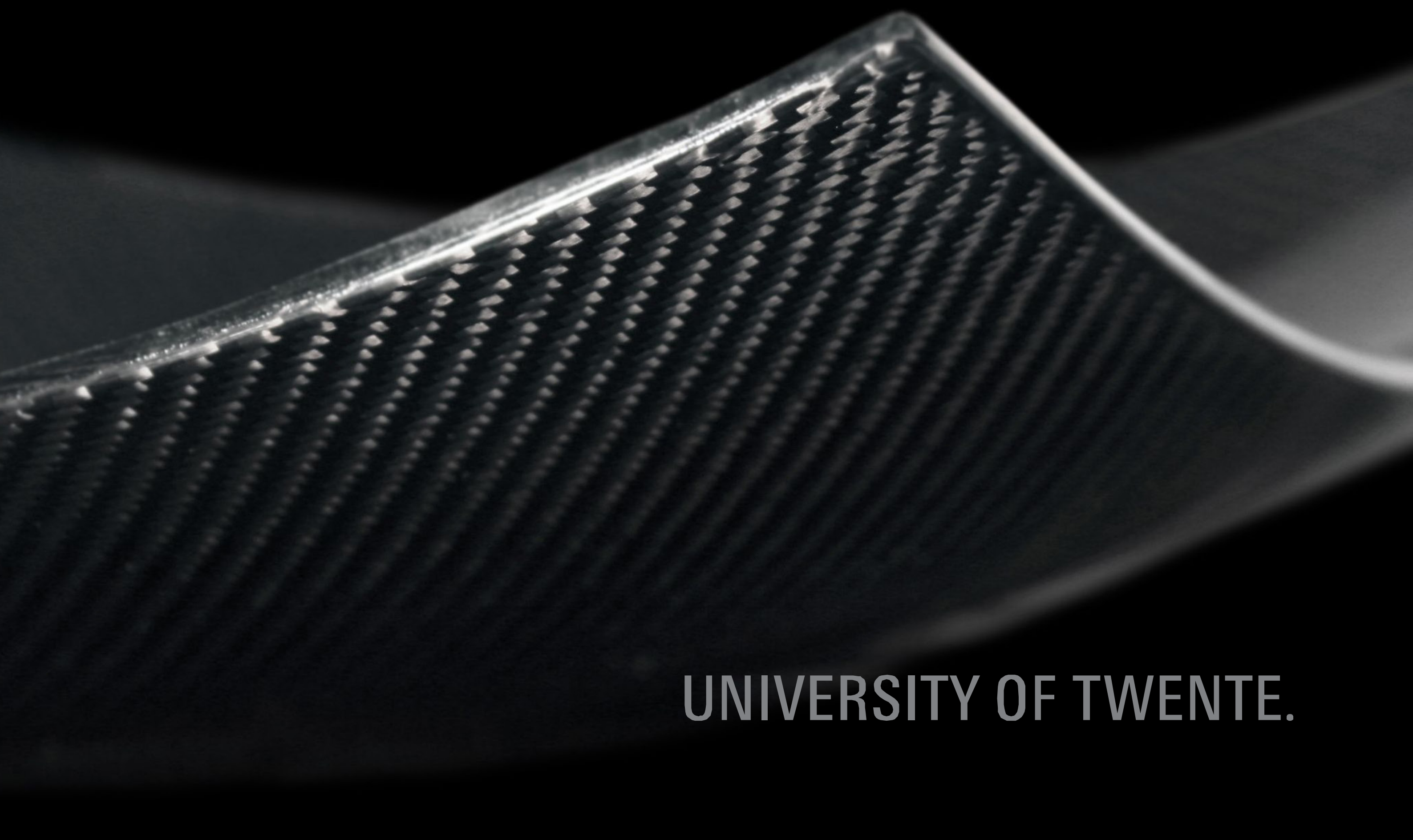
TO ADOPT OR NOT TO ADOPT:

THE CASE OF ADVANCED THERMOPLASTIC COMPOSITES IN THE AUTOMOTIVE INDUSTRY

C.M. VISSER - s0087378

MASTER THESIS INTERNATIONAL MANAGEMENT - BUSINESS ADMINISTRATION - FACULTY BMS - 28.02.2017

1ST SUPERVISOR: DR. A.H. VAN REEKUM - 2ND SUPERVISOR: DR. R.P.A. LOOHUIS MBA



UNIVERSITY OF TWENTE.

TO ADOPT OR NOT TO ADOPT:

THE CASE OF ADVANCED THERMOPLASTIC COMPOSITES IN THE AUTOMOTIVE INDUSTRY

C.M. VISSER - s0087378

MASTER THESIS INTERNATIONAL MANAGEMENT - BUSINESS ADMINISTRATION - FACULTY BMS - 28.02.2017

1ST SUPERVISOR: DR. A.H. VAN REEKUM - 2ND SUPERVISOR: DR. R.P.A. LOOHUIS MBA

UNIVERSITY OF TWENTE.

MANAGEMENT SUMMARY

This thesis aims to provide a study on the constraints of technology adoption in the automotive sector, with a focus on a material substitution. The accompanying research topics are adoption and innovation theories, theory of competitive strategy, and the role of organizational buyers.
The case of this thesis is the adoption of Advanced Thermoplastic Composites in the automotive industry. The research objective is stated as following: finding out which factors could speed up the adoption process of advanced thermoplastic composites in automotive applications.

As technology adoption keeps on influencing businesses and life in general, innovation research is expected to stay an interesting field for the future. By discussing the relevant theories of diffusion of innovation and substitution, the direction of this research becomes a lot clearer. Furthermore, literature about the role of the buyer is also reviewed, which will aid in finding solutions to the problems discovered in the analysis part of this research.

Findings indicate several factors that constrain the adoption rate of ATC. In order to enable further adoption and diffusion of ATC, two recommendations were developed. Firstly, the material supplier should invest in a pilot production line, allowing OEMs and TIERs to see the possibilities with ATC. This test line will function as a proof-of-concept, making the perceived observability far clearer as this allows for a better perception of the possibilities associated with ATC adoption. Trialability will be positively influenced as well, since a pilot line will enable for easier testing and allow to further optimize the manufacturing process to enable high volume production. By experimenting with this pilot line, manufacturing know-how related to these high-volume numbers will be developed more in-depth, perfecting manufacturing techniques. This also enables the ATC manufacturer to estimate and accordingly design their own production process so that it becomes compatible with the demanding automotive industry.

Secondly, licensing partnerships to facilitate the technology transfer of ATC is another way to create more business with ATC. As seen with the Tessera case (Shih, 2010; Hedberg et al, 2009), which describes an example from practice in the electronics industry, it is not always about actual production with the technology at hand. There is a clear need to demonstrate the technology and producibility. Therefore, product technology licensing is a viable option for a supplying organization with patents and trademarked IP. This enables a revenue stream other than the existing way of material production that is sold to industrial buyers. By focusing on potential customers who have a perceived need for lightweighting in automotive industry, the change in strategy will become apparent. This approach could work twofold: first, the rate of adoption of ATC could be improved as other OEMs or TIERs can use and experiment with ATC technology, setting up manufacturing capabilities, thus making it a more acceptable substitute. Of course, all in close cooperation with the material supplier. Second, with each extra licensing project, the costs involved for the supplier will be lower, leading towards a situation in which the initial investments for a pilot line could become a lot more bearable. A return on investment on the innovations related to ATC technology as well as manufacturability can be expected. The

In conclusion, the current situation with ATC resembles a chicken and egg situation; the current demand for ATC stated by the automotive industry is low. The lack of a proper production facility capable of processing ATC at the high-volume level necessary by the automotive industry is not enabling further demand. From the materials supplier perspective, the marketplace needs to be developed. Logically, joint development projects with either TIER or OEM organizations seemed be the way forward, however this approach did not generate any success in the last few years. To persuade the automotive industry to adopt ATC technology, the supplier needs another business model. Also, application development for specific automotive solutions is needed to get the adoption on its way. This lead to the recommendation that a pilot production line is needed, as well as licensing partnerships.

ABBREVIATIONS & LIST OF FIGURES & TABLES

FREQUENTLY USED ABBREVIATIONS

ATC	Advanced Thermoplastic Composites
BIW	Body-In-White (vehicle structure)
CARB	California Air Resources Board
CPP	Cost Per Part
CFRP	Carbon Fiber Reinforced Plastics (composites, both thermoset/thermoplastic)
DMU	Decision-Making Unit
DOI	Diffusion of Innovations
EC	European Commission
ESO	Engineering Services Outsourcing
IDP	Innovation-Decision Process
OEM	Original Equipment Manufacturer
OIP	Organizational Innovation Process, an innovation process model in organizations
SWOT	Strengths Weaknesses Opportunities Threats (analysis method)
TIER	Indicates distance to OEM in the supply chain; TIER1 supplies OEM, T2 supplies T1, etcetera
VC	Value Chain

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

“Finding out which factors could speed up the adoption process of advanced thermoplastic composites in automotive applications.”

1. INTRODUCTION

This thesis aims to provide a study on the constraints of technology adoption in the automotive sector, with a focus on a material substitution. The accompanying research topics are adoption and innovation theories, theory of competitive strategy, and the role of organizational buyers.
In the scientific discourse, the above-mentioned topics are rather well known. However, when put in relation to material substitution, things start to get more complicated. When linking this to the automotive sector, there is hardly any relevant scientific literature available in the field of business administration. Also, material studies are mainly focused on the technological side of the material, and less on its actual adoption potential. Thus, this gap in available knowledge creates an interesting research subject.

1.1 BACKGROUND

The automotive industry is at the brink of a technological revolution. Worldwide rules and regulations about pollution demand cleaner automobiles. Due to the volatile costs for oil and increased environmental awareness, end-users require a more economical way of personal transportation. Environmental concerns have paved the way for a public opinion in favor of cars emitting fewer greenhouse gasses (Schulze et al, 2015). One approach to solving this problem is a change in propulsion technology. Another way is to lower the overall weight of the car. In the form of Advanced Thermoplastic Composites (ATC), a promising technology for lightweight and strong materials has been around for multiple years. In aviation, this material has already been heavily adopted. The potential of advanced composite materials in structural automotive applications has been the subject of discussion for over decades (Beardmore & Johnson, 1986). According to the composites industry, it is now that this technology has the potential to shift from tailored, low volume batches towards mass volume production (Risthaus, 2012). However, the transformation of steel and aluminum parts and/or structures into advanced thermoplastic composites is characterized by a low speed of adoption. At this moment, no ATC application of any significant scale or magnitude is taking place. The question rises as to why this is the case. The automotive value chain is known for its high capital intensity, so economic factors are most certainly of influence. And as safety is of major concern in this industry, technological concerns with regard to new materials are to be expected as well.

For over a decade the automotive industry has been experiencing turbulent times. Changes in ever global markets, governmental regulations and technological advances are the engine behind a set of innovations that influence the automotive industry on an unprecedented scale and scope (Schulze et al, 2015) Given the pressure on the automotive industry to make greener and safer vehicles, a lot of ongoing investment in R&D is made. Design efficiencies using advanced materials and technologies are increasingly important factors for vehicle material composition. Given the relatively low number of OEMs, the capital intensity and its subsequent high entry-barriers, the automotive industry can be regarded to have oligopolistic traits. This restricts the leeway each OEM has, as each firm's decision influences and is influenced by decisions of others firms. Each oligopolist will know more or less the actions of its competitors, and to adopt a technology stemming from another industrial environment will be difficult to pursue without letting the competition know. However, the change from steel to other materials is no straightforward process and at this moment in time, no best-practices or optimal way for a lightweight car have been determined. Technologies regarding design, manufacturing, testing and processing are further areas for innovation, leaving the door open for several strategies to material usage.

The automotive supply chain is usually described as a multi-tier supplier structure, whereas in the past, OEMs used to have a high degree of vertical integration. The origin of this shift towards outsourcing stems from the widely accepted idea among OEMs that "only a specific subset of vehicle components actually provide a distinct competitive advantage" (Bernhart et al, 2010, p13). As OEMs remain stable in their role as system integrators, these organizations stay dominant over product architecture and supply chain dynamics (Schulze et al, 2015). Components or sub-modules that do not bring about competitive advantage are outsourced to Tier1 suppliers. The trade-off of internal development or external contracting of a third party is one that OEMs frequently have to go over. This process is called Engineering Services Outsourcing (ESO). Furthermore, the current market downturn puts pressure on the OEMs, forcing them to search for more flexible R&D structures, thus enabling them to react quickly to changing market directions. There is however a friction at the side of the OEM and its TIERs: pricing, produce ability, reliability of material, developmental costs and time; all conditions that play a role in the perceived adoptability rate. To reduce uncertainty and costs, this technological substitution often goes incremental as different materials such as alloy and steel can be combined with thermoplastic composite parts (Risthaus, 2012). It is relevant to comment here that in automotive, R&D expenditures made by suppliers account for two-thirds of the tot the total (Wyman report, 2013). It is therefore logic to conclude that innovation is more supplier-driven than demanded by OEMs.

The diffusion process of structural thermoplastic composites in automotive is still at its birth phase. Strictly speaking, this should be taken as a substitution matter. However, given the complexity and uncertainty it is surrounded by, as well as the fact that hardly any substitution has taken place, the innovation seems to be 'stuck' in this adoption phase.

1.2 RESEARCH PROBLEM

Market estimates of advanced thermoplastic composites (ATC) in the automotive industry indicate an enormous potential for material substitution. In addition to other lightweight solutions, this material could prove to be one of the go-to lightweight materials of the mainstream car of the future. These opportunities arise as the cap on emissions gets more stringent by the years.

By acknowledging the potential market in automotive and the need for cleaner and more economical automobiles as mandated by regulations, a great opportunity arises for suppliers (TIERs) and manufacturers (OEMs) to fulfill this gap.

Because of the complex, capital intensive automotive value chain and scarcely available knowledge about the constraints in automotive adoption processes, it is difficult to determine which factors can speed up the adoption process.

1.3 RESEARCH OBJECTIVE AND RESEARCH QUESTIONS

RESEARCH OBJECTIVE

"Finding out which factors could speed up the adoption process of advanced thermoplastic composites in automotive applications".

By looking at past adoption cases (aluminum, high strength steel) and predictions for future automotive materials, an insight will be gained in the constraints of this adoption process. The interviews will try to verify these views, and enhance the understanding of the constraints to this innovation adoption.

MAIN QUESTIONS

1. What are the substitution constraints for buyers of automotive thermoplastic composites?
   These constraints are expected to be technological or economical of nature. An example of a technological constraint is the extra complexity ATC technology is expected to have in comparison to steel. Economic constraints could be the high investments needed and the resulting higher costs per part (CPP).

2. How can these constraints be solved or neutralized?
   By analyzing the nature and scope of these constraints to this innovation adoption and substitution, a pragmatic approach to this adoption problem will be formulated.

SUB-QUESTIONS

In order to answer the main questions, the following sub-questions were developed:

1. What are the relevant theories about innovation adoption and diffusion, and what is the link to substitution?

2. How can the prior conditions to this innovation adoption be described?

By looking at previous practices, felt needs/problems, innovativeness, norms of the social systems, the influence of the conditions prior to the innovation decision process can be described.

The first aim here is to find out what demands are present in the current automotive environment with regard to a material substitution. Regulations will be discussed briefly as well, as this will enable to pinpoint the situation the automotive industry is currently facing. The second aim here is to find out more about prior decision-making conditions, leading market requirements and regulations influencing this substitution.

Answering these questions will enable us to further examine the innovation adoption process.

1.4 RESEARCH DESIGN

This research tries to find answers for the adoption problem as stated in the previous paragraphs. A situation with such complexity implies the use of a case study, which enables a researcher to examine things in-depth. In order to study the several factors and dynamics more profoundly, a qualitative research method will be put to use (Verschuren & Doorewaard, 2007).

To analyze the adoption case at hand, the following independent factors (constructs) were taken from Diffusion of Innovation (DOI) theory (Rogers, 2003). Relative Advantage and Compatibility are innovation characteristics that can be seen as independent factors. These constructs are expected to have great influence on the speed by which the specific adoption process will take place. The dependent factor, the adoption process itself, has to be explained by these two factors. In schematic form this looks as following:

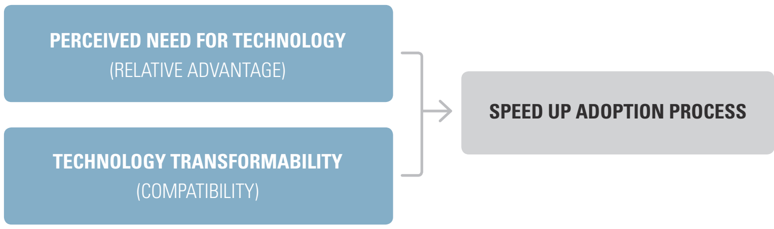


FIGURE 1 Conceptual model

Relative advantage, or perceived need for technology, is the degree to which an innovation is perceived as better than it supersedes. This factor is measurable in economic terms, social-prestige factors, convenience and satisfaction.
Compatibility, or technology transformability, is the degree to which an innovation is perceived as being consistent with the existing values, past experiences, and needs of potential adopters (Rogers, 1983). Compatibility could also

refer to operational compatibility, however as this research has no focus on the practices of the adopters, there is no need to directly investigate the operational side of this construct (Tornatzky & Klein, 1982). An innovation that is not compatible with the potential adopter will not be adopted as rapidly as an innovation that is compatible, and vice versa. The adoption of an incompatible innovation often requires the prior adoption of a new value system (Rogers, 2003).
The measure of adoption process, or rate of adoption, is the relative speed with which an innovation is adopted (by members of a social system).

Given that within adoption decisions there are other innovation characteristics at play, this model could be oversimplifying the situation. However, the perceived need and the technology transformability are the two main factors expected to have the largest influence on the adoption process, and therefore are regarded here as the most relevant. A meta-analysis of the work on innovation characteristics found that these two characteristics (among others) mentioned in this conceptual model, have been related consistently to adoption success (Tornatzky & Klein, 1982; Straub, 2009).

1.5 RELEVANCE

SCIENTIFIC RELEVANCE

As stated in the introduction, In the scientific discourse, the above mentioned topics are rather well known. However, when put in relation to material substitution, things start to get more complicated. When linking this to the automotive sector, there is hardly any relevant scientific literature available. As a result, this gap in available knowledge creates an interesting research subject.

SOCIAL RELEVANCE

This thesis was partly written at the site of the New Business Development (NBD) department at the advanced composites division of a Dutch company. Here, functional materials are developed and produced by combining textile technology with chemical processes. This means that the composite materials are fiber reinforced, combined with thermoplastic resins. While the focal division has a track record in aerospace and non-armor related composites, it is NBDs task to expand the composite business to the automotive industry. If their market entry to the automotive industry were to be executed successfully, it would be quite beneficial to society in the form of jobs and other economic benefits, especially for the Twente region.

From a larger scope, end-users of more innovative automobiles would benefit by higher safety standards and a better mileage. Societal benefits would be fewer greenhouse gas emission and consequential lower medical costs.

1.6 OUTLINE

The remainder of this thesis is structured as following:
In chapter two the relevant literature regarding DOI theories and substitution will be provided. Also, the buyer roles as distinguished in the organizational buying process are discussed. By discussing the relevant literature, the first sub-question can be answered.

Chapter three will elaborate on the research design, the collection of both primary and secondary data and issues regarding the respondent selection.

Chapter four contains the analysis and discussion of the collected primary and secondary data. The first two paragraphs contain the interview data and its subsequent analysis. The table in this part gives a summarized answer to the first main-question. The third paragraph describes automotive adoptions that have materialized, as well as laws and regulations that influence the adoption decision. This allows for answering of the second sub-question. Based on both data sources, a SWOT analysis of ATC is presented. By rounding up the findings, the second part of the main research question can be answered.

In the final chapter five, the conclusion about the case study is stated and further discussed in the recommendations for adoption decision. Then, it is time to point out the limitations of this research, followed by the opportunities for further research. Finally, the contributions of this thesis are discussed as well as a reflection on the process of this research project.

CHAPTER 2. THEORETICAL FRAMEWORK

"Reviewing the relevant theories of diffusion of innovation, substitution and the buying process, which will aid in finding the direction of this thesis."

2. THEORETICAL FRAMEWORK

The decision to adopt a particular technology and the time window involved has been a topic of extensive research for years. As technology adoption keeps on influencing businesses and life in general, innovation research is expected to stay an interesting field for the future. By discussing the relevant theories of diffusion of innovation and substitution, the direction of this research becomes a lot clearer. Furthermore, literature about the role of the buyer is also reviewed, which will aid in finding solutions to the problems discovered in the analysis part of this research.

2.1 INNOVATION IN LITERATURE

Innovation research is a broad field with an extensive body of research. Subjects range from diffusion and adoption of innovations, as well as innovating and innovativeness studies. Although there is overlap between these concepts, this research has a focus on the adoption of innovation in organizations which encompasses the generation, development and implementation of an innovation (Damanpour, 1991).

2.1.1 DIFFUSION OF INNOVATION THEORY

Technological innovation is a concept that is widely used in business language yet it risks becoming mere rhetoric when its definition is not clearly stated. Rogers (2003) operationalized the concept as "..an idea, practice, or object that is perceived as new by an individual or other unit of adoption". It is therefore heavily related to the perceived 'newness' as this definition implies that an innovation itself does not have to be objectively new. Diffusion then, is defined as 'the process by which an innovation is communicated through certain channels over time among the members of a social system'. How innovations diffuse and become adopted is what Diffusion of Innovations (DOI) theory aims to explain. This can be done by analyzing its characteristics, the types of communication channels used over time, among the social system in which the innovation is diffused.

- The innovation characteristics, or the perceived attributes of an innovation, are:
- Relative advantage, i.e. the degree to which an innovation is better than an existing method/practice/idea. The relative strengths of a specific innovation positively influence adoption.
- Compatibility, i.e. the degree to which an innovation matches the needs, experiences and views of the potential adopter. A high compatibility positively influences the likeliness of adoption.
- Complexity, i.e. the degree to which an innovation is perceived as relatively difficult to use or understand. E.g., a high complexity slows down the diffusion rate of the adoption and the actual adoption decision will appear less likely.
- Trialability; i.e. the degree to which the innovation may be experimented with before committing to adoption. If easy testing is possible, adoption will be a more likely decision.
- Observability, the degree to which the results of an innovation are visible to others. The easier it is to see the innovation's advantages, the faster it will diffuse.

In schematic form, the model looks as following:

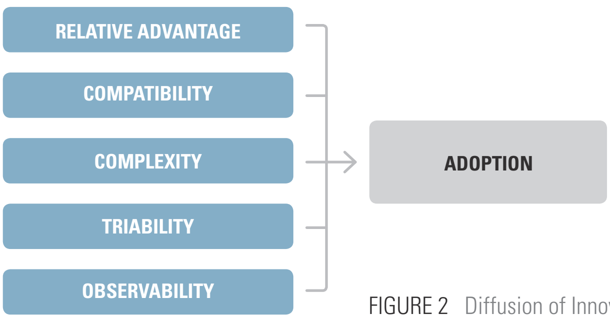


FIGURE 2 Diffusion of Innovation model (Rogers, 2003)

The perception of the innovation characteristics help explain the rate of adoption of an innovation. A note of criticism regarding Rogers' theory is that although it "..provides a foundational understanding of adoption theories..", it is not always easily applied to understanding adoption (Straub, 2009). Due to its bread and depth, DOI can be used for understanding individual adoption and collectively, diffusion. DOI has been used broadly across disciplines to comprehend and predict change. It remains however difficult to apply DOI to understanding adoption decisions, especially one that is still in progress like with the case with ATC in the automotive industry. Adoption of a new technology often boils down to the individual level, even though the actual decision making takes place at a higher organization level (Straub, 2009). This is where a subtle distinction between the related concepts of adoption and diffusion of innovation becomes visible. Diffusion theory looks at innovation from a "..macroperspective on the spread of an innovation across time", whereas adoption theory focuses on the 'microperspective on change' (Straub, 2009, p626). As these concepts are interrelated and often used in close distance, literature refers to it as adoption-diffusion theory. It remains however a notable difference in the way innovation is approached. The following figure explains the difference and correlation between the two concepts more concisely, as it shows how individual adoptions compose innovation-diffusion:

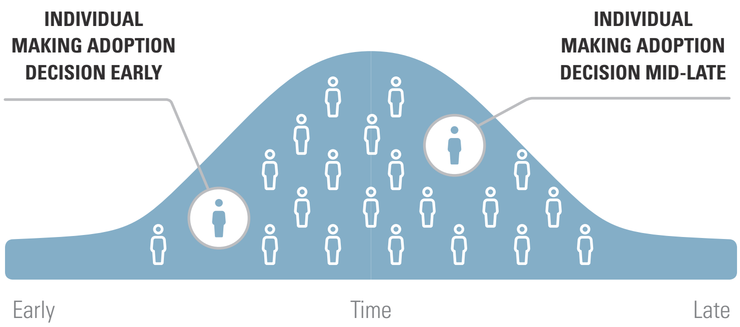


FIGURE 3 How individual adoptions compose diffusion (Straub, 2009)

Furthermore, adoption includes the initial evaluation of an innovation and a commitment to use this innovation on all subsequent occasions possible (Olshavsky & Spreng, 1996).

2.1.2 OTHER INNOVATION MODELS

Other theoretical models that enable researching innovation are either focused on the adoption decision on an individual level (TAM, TAM2, UTAUT), or are tailored too narrowly to a specific innovation case that it would require a lot of model redesign to make it applicable to another context (UTAUT, TBAM). The models are also rather static in their nature, making it difficult to study innovation adoption whilst in progress.

The Technology Acceptance Model (TAM) has an IT origin, as it was developed to predict computer usage. It is used for determining factors that explain acceptation and usage behavior of the technology at hand. (Pijpers et al, 2001). A drawback of the TAM model is that the external variables have not been fully investigated. TAM2 is a revised version of TAM, with a more extensive elaboration of the external variables.

The United Theory of Acceptance and Use of Technology (UTAUT), is the newest model. It shares theoretical aspects with TAM and DOI, which it uses in parts of it. The focus of the model is to predict usage behaviors, based on behavioral intention that was shaped by performance and effort expectancy, and social influence.

The Concerns-Based Adoption Model (CBAM) provides the perspective of how the concerns of an individual influence the adoption decision. It approaches innovation from the perspective of the adoptees in an education setting (Hall, 1979; in: Straub, 2009). Adoption-decisions analyzed with this model often that are top-down mandated innovations. It's context and focus on the concerns of individuals make it inapplicable to the case of this research.

Since the plethora of adoption theories has thus far failed to deliver a fitting, 'unanimous' innovation model directly applicable to the case of this research, another approach had to be taken. Going back to Rogers' DOI theory, the broadness of it means that it also provides multiple ways of analyzing the same problem. Thankfully, for researching an innovation-decision in progress, another model is available. As part of DOI theory, the innovation-decision process (IDP) will serve as a guidance in this research. The models do however provide insight into how innovation is usually studied, namely at the individual level, often in a context specific environment (IT, education systems, farming).

2.1.3 INNOVATION-DECISION PROCESS (IDP)

In order to develop a better understanding of what is happening in this adoption case, a less static, broader model is needed. Luckily, there is. When an innovation is adopted by either an individual or an organization, all go through similar stages described in the innovation-decision process (Rogers, 2003, p170). A schematic depiction of this model looks as following:

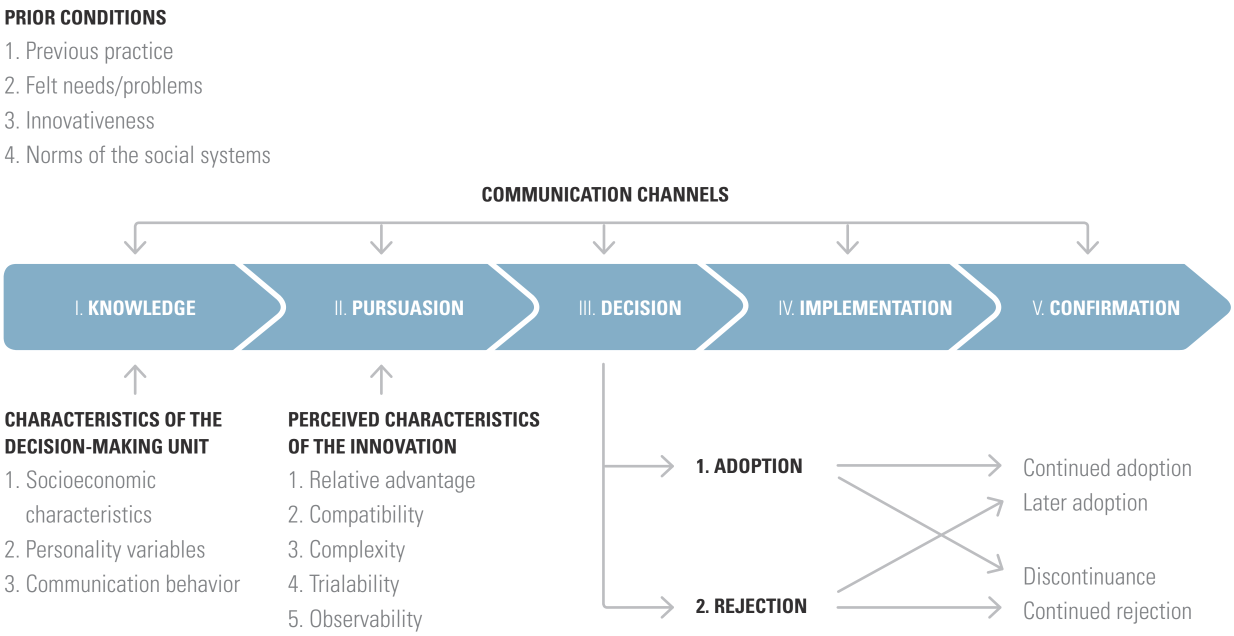


FIGURE 4 Stages in the innovation-decision process (Rogers, 2003)

As the current rate of adoption of Advanced Thermoplastic Composites is rather low, it appears that the cause for rejection (or; non-adoption) can assumedly be found in either the persuasion or possibly even the knowledge stage. The innovation efforts by OEMs and TIERs are often a joint effort with similar interest in innovation adoption and implementation. Since these decision-making units (DMU's) are organizations with generally high requirements regarding education and professional experience, knowledge about and understanding of the existence of an innovation should not be a problem. Due to this awareness at the adopter side, the socioeconomic characteristics and personality variables are assumed to be of less influence. The communication behavior could however be an issue, for example when there is 'noise' inferring the discussion about certain aspects of the technical innovation.

The second stage, persuasion, is where the individual or DMU forms an attitude towards the innovation. This attitude can be favorable or unfavorable. The perceived characteristics were already discussed in paragraph 2.1.1 about DOI-theory. The route towards an adoption decision does not take place in a vacuum as beliefs and attitudes are formed over time. This may in turn influence the adoption decision (Straub, 2009).

2.1.4 THE INNOVATION PROCESS IN ORGANIZATIONS

Different from focusing on individual adoption decisions, the innovation process in organizations deserves its own model. As the unit of adoption are organizations, there is a risk that focusing on the individual within an organization (and its individual innovation adoption decisions), leads to oversimplification. Looking at organization innovativeness, this approach can be used to study variables of innovative and less-innovative organizations. This is outside the scope of this research. To study innovation diffusion among organizations as if it were an individual deciding about adoption of an innovation, the organizational innovation process (OIP) model provides a good oversight. Characteristics and models from the individual level can be and were applied to organizational innovation studies. This helped determining the variables related to innovative and less-innovative organizations. The innovation process within organizations however, has more focus on how the innovation is going to be put into use by implementation (Rogers, 2003, p417). This has resulted in the following two-stage model:

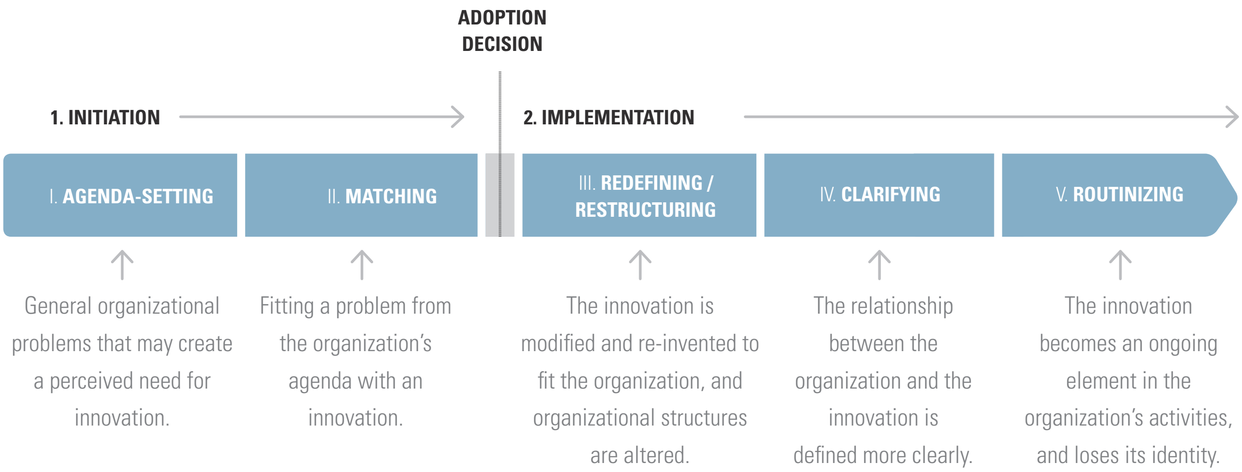


FIGURE 5 Organizational Innovation process (Rogers, 2003)

The general assumption of research on innovation in organizations is that organizational variables act on innovation behavior in a manner over and above that of the aggregate of individual members of the organization (Rogers, 2003, p418)

The rate of adoption can be represented by an S-curve which depicts the cumulative innovation adoption over time. As adopters are low in the beginning of the curve, this gradually rises as there are few early adopters. This normal-distributed process eventually slows down as saturation or (near) full adoption is reached (see also figure 3). It has to be noted, however, that this curve is innovation- and system-specific and can only be drawn post-adoption, when the innovation has successfully been diffused among the system members. The technology adoption of ATC by the automotive industry is currently perceived to be at the very bottom of this curve, and it remains unclear if and how this adoption is going to take off in the same way as earlier adoptions, or that non-adoption will occur.

CATEGORIES OF INNOVATION

The following four categories are considered to impact the relationship between organizational factors and innovation (Damanpour, 1991):

1. Type of organization: service or manufacturing, for-profit or not-for-profit)
   All types of organizations adopt innovations to respond to changes in their external and internal environments. Organizational factors may influence innovation differently based on the type of organization, as well as the context and the industry can influence innovativeness.

2. Types of innovation: technical or administrative, radical or incremental, product/service or process
   Radical innovation produces fundamental changes in the activities of an organization and represent clear departures from existing practices. Incremental innovation results in little departure from existing practices variation and routine and instrumental innovations. Product innovation occurs when new products or services are introduced to meet an external user or market need. Process innovations have new elements introduced into an organizations production or service operations (e.g. input materials, equipment used to produce a product).

3. Stage of adoption: initiation or implementation
   Based on Rogers' OIP (figure 5), innovation adoption is conceived as a process that includes activities that lead to a decision to adopt as well as activities that facilitate putting an innovation into use and continuing to use it.

4. Scope of innovation: low or high
   By looking at the number of innovations adopted in a given time period, the innovativeness of an organization can be measured. Studies of single innovations and their adoption process are essential to understanding the generation, development, and implementation of innovations in organizations. However, low scope studies ignore the fact that organizations, especially large ones, adopt many innovations in a given time period. Results of those studies may reflect the attributes of the innovations studied more than the characteristics of the organizations. Multiple innovation studies are also needed because these enable identification of the characteristics that facilitate innovation adoption are necessary in the design and management of innovative organizations (Damanpour 1991, p582)

2.2 SUBSTITUTION

Using the Five Forces Framework (FFF) by Porter (2008), the configuration of underlying economic drivers that influences industry profitability can be analyzed. This will explain a lot about industry dynamics, as the level of analysis is a lot higher than in the first paragraph. Although making a full analysis of the automotive industry according to the FFF would be challenging and interesting, for this research paper makes more sense to zoom in on one force in particular: the threat of substitutes.

The introduction of thermoplastic composites to the automotive industry is in essence the replacement of other materials such as steel or aluminum. In strategic terms, this introduction is called a 'threat of substitution' towards these existing materials (Grant, 2010). Based on Porter's renowned Five Forces Framework, this substituent, competing offering becomes apparent when it is perceived by the buyer as a justified alternative to existing offerings. A solid price and performance trade-off will positively influence the decision making process on whether or not to go through with the substitution. In economic terms, substitution is influenced by price elasticity of demand, i.e. customers switching to alternatives based solely on price changes. This rudimentary view of predicting substitution behavior becomes troubled when taking performance characteristics in consideration (Grant, 2010). Complexity and specific characteristics as recognized by the customer make price less important. When a complex substitute is being promoted, it is therefore logic to focus on both this complexity and specific characteristics that make it stand out of the competition. Price, although not unimportant, is of lesser importance. However, the technology behind thermoplastic composites is advancing, creating other substitutes as well as shift price-performance comparisons in favor of this material. At the same time, the availability and performance of complementary producers might increase, shifting the threat of substitution (Porter, 2008, p35).

Other quantitative methods to calculate the performance of an array of substitutes, e.g. performance/cost, enable a reasonable comparison of the performance of the material substitution (Farag, 2007). Especially when calculating different substitution scenarios by a compound objective function (COF), it is a necessity to know which different performance requirements are around. Within this method, a relative weight is given to each requirement, followed by a comparison with candidate materials which are held against the currently used material on a weighted sum of all the normalized material performance requirements. As a result, various scenarios come up after assigning different weighting factors (Farag, 2008). In order for substitution to take place, the material needs to score higher on the COF scale than the material currently used.

In automotive, pitfalls of substitution are a lack of understanding of characteristics of the new material, as well as a missing review of the component design (Farag, 2008). The new material should be utilized optimally, benefiting from the full potential a new material inhibits. This will enable the new material to exploit "..its properties and manufacturing characteristics.." to the fullest. If these pitfalls are not considered during pre-production phases, then things could end up badly, needing a full re-design of an existing component. Not only will this slow down the innovation at hand, it will most likely have a bad influence on the value perceived.

FAILURE DRIVERS AND SUBSTITUTION PARAMETERS

By substituting existing materials, a clear understanding of all characteristics of the new material should be available. Failing substitutions are mainly originating from a lack of insight in the long-term properties, leading to unwanted effects of the material behaving in the design. Another driver of failure is the lack of a proper design review in which the material is to be implemented (Farag, 2008, p374).

Another driver for failure could be distinguished as 'part-for-part substitution', which can be seen as a modular design. This is known to lead to a less than optimal utilization of the new material. Although not explicitly mentioned by this author, a distinction between the substitute supplier and the implementing buyer seems to be necessary when estimating the failure risk within a specific failure driver.

Farag (2008) distinguishes the following parameters that need examination for material substitution

- Technical performance advantage, e.g. stronger, tougher, or lighter material
- Economic advantage over the total life cycle of the product, e.g. lower costs (processing, running, disposal), better recyclability
- Product character change, e.g. providing more comfort through sound insulation
- Environmental and legislative considerations, e.g. compliance with environmental regulations

These parameters can be calculated on a performance-cost basis. This method entails a comparison between the weighted performances of candidate substitution materials against the currently used material. Performance here covers all requirements of the material except costs. This approach has several possible outcomes, all of which depend on the main substitution objective, which will be a tradeoff between a performance increase or cost reduction.

FACTORS DRIVING SUBSTITUTION

From OEM point of view, the introduction of advanced thermoplastic composites is to be described as critical purchase item. Both the impact on internal VC issues as well as the supply risk are high, meaning a lot of risk is involved. Technology lock-in, increasing supplier dependency and high switch costs are a few that come to mind. The pay-off is in theory a higher profit margin and the possibility to implement technologically more advanced lightweight designs into the car. Because current parties in existing VC's lack the knowledge to work with thermoplastic composite, cooperation is key here. This takes a lot of time prior to actual production. According to the composite industry, the estimated horizon is between one and three years from initial conversations to having the production capacity ready for mass production.

Farag (2008) emphasizes that in automotive, substitution is mainly driven by cost reduction, increases in fuel economy, improved aesthetics and comfort, and compliance to new legislation. Weight reduction in one area enables a subsequent reduction in other areas. I.e., a lighter vehicle would perform equally well when equipped with a smaller engine than its heavier counterpart.

2.3 BUYER ROLES

After having considered the process of innovation decision making, and its relation to substitution, the role of the buyer remains unexplained. The behavior of industrial buyers is readily discussed in literature, and will be discussed next.

Organizational buying, comparable to the IDP, is a complex, decision-making process that takes place in an organizational setting. Multiple individuals are involved in what is called the 'buying center' of an organization, with each member having potentially different goals and intentions. Interaction between these individuals is therefore of great importance. The buying process is regarded as a problem-solving process as it tries to close a perceived discrepancy between a desired outcome and the present situation (Webster & Wind, 1972).

Within the buying center, the following roles are identified:

- The users who use the purchased products/services
- The influencers 'steer' the decision process directly or indirectly by providing of information and criteria for evaluating alternatives, reducing uncertainty
- The deciders are those with the authority to choose among buying alternatives
- The buyers, have formal responsibility and authority for contracting with suppliers
- The gatekeepers control the flow of information into the buying center

By focusing on who performs which activity, both on the individual and organizational level, and also on the underlying reason why certain activities are performed, a more complete picture of the buying process can be generated (Niciosa & Wind, 1977). Factors influencing buying behavior are internal (e.g. technological know-how, financial strength) or external (e.g. laws and regulations, competitive pressures). If an organization is planning to buy a technology innovation, the roles concerned need to be correctly identified and potential supplying organizations should ideally be in the 'loop' of the buying process.

A buying situation is created when someone in the organization perceives a problem for which the solution could be sourced externally. When buying technology, this might ask more from existing production plants and their current equipment than is anticipated. For example, a new material could need substantial changes in production methods, or personnel skills. Technology then, "..influences both what is bought and the nature of the organizational buying process itself" (Webster & Wind, 1972, p17). Risk reduction or uncertainty avoidance are other ways for buyer to stay loyal to its existing sources. Any buying problem can be defined as a set of product, supplier and salesperson attributes, forming the basis of buyer needs (Möller, 1985). These attributes are usually not equally important, depending on the buyer. At times, certain attributes have to pass threshold values such as a specific price and technical specifications.

DERIVED DEMAND

One specific area of substitution thus far not discussed involves the nature of demand. When the demand for a product is generated by forces outside the buying organization, it is called 'derived demand' (Webster & Wind, 1972). With regard to ATC, when this material becomes adopted and implemented, it is likely that this will affect the willingness to use this material in other areas as well. In other words, the adoption of ATC is likely to start demand for this material in other applications, thus creating derived demand. This is only a side-effect of innovation adoption and substitution, but nevertheless needs to be mentioned as this can accelerate future rates of adoption.

2.4 CONCLUDING REMARKS

Technology adoption and diffusion theories describe a complex, inherently social process. Each individual concerned shapes their own perception of technology which influences the adoption process. The resulting perceptions can be influenced to some extent, however this is expected to slow the adoption rate down considerably. Due to the early stage of the adoption case at hand, the first three stages of the IDP, knowledge, persuasion, and decision appear to be of most relevance to this research.

The adoption decision that is the core of this research, cannot be taken individually. This renders traditional innovation models focusing on individual adoption decisions less useful. Also, the applicability of these theories to the adoption of technological innovations on the organizational level has been questioned (Elbertsen & Van Reekum, 2008, p3). The broader innovation decision process (IDP) however, does allow for a better understanding of the overall process of adoption by considering the innovation characteristics. Distinguishing the type of innovation is necessary for understanding organizations' adoption behavior (Damanpour, 1991).

The organizational buying process is an interactive process with several individuals involved. Distinctive buyer roles were discussed, as were the different factors involved in the (non)buy decision. A buyer's preference to keep the things at the current status quo would be devastating to an adoption decision. Combined with a high perceived risk without proper ways to reduce this risk, avoidance to buy and therefore to adopt a technology, the diffusion of such an innovation becomes an increasingly difficult task.

Technology adoption and substitution are concepts related in a way that the one can start the other. An innovation adoption can lead to substitution, and when the innovation becomes diffused on a higher level, substitution of incumbent products by the innovation is most likely to appear. Substitution on the other hand is almost always an innovation of sorts. This paragraph then answers the first sub-question, "What are the relevant theories about innovation adoption and diffusion, and what is the link to substitution?:

CHAPTER 3. METHODOLOGY

"Discussing the used methodology including research design, sources of data and issues related to the data collection."

3. METHODOLOGY

The main focus of this thesis is to find out which factors could speed up the adoption process of advanced thermoplastic composites in automotive applications. In this chapter, the used methodology will be discussed. As the theoretical framework of the previous chapter was used to guide the research, this deductive approach lead to a series of questions about the adoption process that demanded the gathering of empirical data.

3.1 RESEARCH DESIGN

Given the early stage of this adoption problem in the diffusion curve, the need for qualitative data became apparent. This needed data was to be gathered at the (potential) adopters group. The units of analysis here are the TIER/OEM organizations that either make or have to deal with the consequences of this adoption decision. In order to find out about their views on ATC, the stage of their adoption process, the envisioned constraints and other factors influencing adoption, the interview method was selected. To be more exact, semi-structured interviews were selected as the proper way to gather data. Respondents should ideally be individuals working at decision-making positions. The unit of observation, therefore, is at the individual level.

3.2 DATA COLLECTION

To allow for a case study to become more accurate and convincing, several different sources of information are needed to enable an empirically sound line of reasoning. Primary data was collected through interviews, and personal observations. Secondary data was another source of data.

3.2.1 SOURCES OF DATA

The main source of data collection were the interview sessions held with 3 employees of an OEM, and 2 employees of a TIER one organization. Another source of primary data were the observations made made during an internship at a Dutch material supplier.

The interviews were semi-structured with open-ended questions. A semi-structured interview involves a question set that enables consistency along each interview, while it also enables respondents to elaborate on their answers into more detail. This meets the expected complexity of responses from the participants, and this enables exploration of areas that are of similar importance. Since it is highly unlikely that a fixed set of questions would suffice to get all needed information, the open-ended questions give way for further questioning. The interview protocol can be found in Appendix A.

Another source of data was the secondary data gathered from trade journals, technical literature. As the following subparagraph will explain, access to relevant market data and insights was hard to gain. Therefore, the use of secondary sources was needed as this qualitative secondary data allowed for reanalysis of the information (Verschuren & Doorewaard, 2007) in the light of a different case study. This allowed a better analysis of the adoption cases in automotive industry, as well as to include the main regulations that influence this industry.

3.2.2 RESPONDENT SELECTION

Ideally respondents were selected from different parts of the OEM or TIER organization, preferably related to strategic DMU's or at least capable of providing insight in the adoption decision making at other levels in the organization. These respondents could be industry insiders working at an OEM or TIER organization, in a middle to higher management position. However, as respondents were very difficult to contact, and the automotive organizations were apparently rather cautious with their information sharing, some alterations to the initial research approach had to be made. As the needed data was either unavailable inside TIER/OEM organizations, or raw market data behind a paywall, the actual collection became more a case of ‘who is willing’ or just plainly available, than being able to truly select the best respondents out of a pool of available people. One set of three respondents who were willing to participate, did so but only on their terms. At this point in time, some data to be gathered seemed better than none. This meant the semi-structured interview questions were sent by email, and after thorough answering from the responding three, a short teleconference was allowed to discuss any loose ends. This seriously impeded the opportunity to collect multiple visions of the same adoption decision, all in the same organization but in different parts.

CHAPTER 4.
DATA ANALYSIS

"Analyzing the adoption process and issues according to both the interview findings as well as secondary sources on automotive innovation adoptions. Both leading to a SWOT analysis of ATC and the answering of the main research questions."

4. DATA ANALYSIS

By analyzing the primary data as gathered by the interviews, the adoption potential of ATC by the views of the respondents is discussed, as well as the constraints of adoptions. Secondary data with previous automotive adoptions, rules and regulations and their impact on adoption, are mentioned as well. The analysis finally tries to close the gap between the detected constraints and a solution to overcome them, by answering the central research questions: What are the substitution constraints for buyers of automotive thermoplastic composites? and: How can these constraints be solved or neutralized?

4.1 INTERVIEW ANALYSIS

The analysis is structured on the basis of the different stages mentioned by the Innovation-Decision process. In a similar way the IDP was used as a guidance for the questionnaire. The following paragraph is meant to give a detailed view of the answers given by OEM and TIER employees.

PRIOR CONDITIONS TO THE IDP

Felt needs and problems come together in the already defined need for lightweight, strong materials. Both the OEM and the TIER are aware of this. See also: knowledge stage of this paragraph.
The organizational environment for OEMs is mainly influenced by regulations. Also, competitors create a good benchmark for the screening of products, comparison of requirements and solutions.

FIRST STAGE IDP: KNOWLEDGE STAGE

The first stage of the IDP, knowledge, proved to be of no threat to the adoption decision of ATC. As the interviewees at both the OEM and TIER indicated the perceived need for automotive lightweight materials and had proper knowledge about composite materials being an enabler in this. The following quote by a member of the OEM organization underlines this: “Thermoplastic composites could help to find a compromise between performance requirements and part-costs. Whereas thermoset-solutions are much more expensive than conventional ones, thermoplastics can help to narrow the cost-gap.”
The TIER organization underlines this non-lack of knowledge: “The market knows (about the existence of, edit author) composites,(..) sees the advantages but also the struggles.”. By composites, here no special distinction between thermoset or thermoplastic, advanced or non-advanced is meant.

SOCIOECONOMIC CHARACTERISTICS

These characteristics, although of importance in the individual adoption-decision, are of less importance here and were not discussed in the questionnaire. See also paragraph 2.1.2 where this is briefly discussed.

COMUNICATION BEHAVIOR DMU

Between (potential) suppliers and OEMs, there seems to be a high amount of openness when a supplier wants to discuss ideas about potential applications with the OEM: “Any idea and technology trend is constantly being discussed with all stakeholders concerned based on strategic roadmaps, vehicle projects, potential application and innovation potential”

From TIER perspective, it is important to know which person(s) to approach for enabling a dialogue about a new development for an application. Sometimes, however, it is the other way around; when an OEM encounters a problem in the development stage and wants support in working towards a solution. If the right TIER is found, this could lead as a start to a joint development.

SECOND STAGE IDP: PERSUASION STAGE

From TIER perspective, when in their role as ‘innovator’, a lot of promotion regarding their innovation is directly aimed towards the OEM. This results in direct contact with the OEM’s contact person or change agent, and leads ideally to an adoption decision that enables joint development of the innovation. As the ‘green light’ decision lies at the OEM organization, implementation of the innovation in the production process awaits as the next phase.

RELATIVE ADVANTAGE

According to both the TIER and OEM, the relative advantage of ATC is depending on the application. Different requirements and settings for lightweighting such as design features, number of produced parts, all influence the relative advantage ATC has in a specific application. Next to the obvious material properties (stated as strengths in the SWOT analysis, paragraph 4.3.3), the following was mentioned as rather notable relative advantages:
By explanation from the TIER, it is their experience that with thermoplastic composites, residual waste is lower: “With steel, you end up with lots of waste when cutting, pressing etcetera. (..) This is different to thermoplastic composites where for some applications you hardly have residual waste.” This also goes up for ATC’s. Another advantage is the recyclability or down-cycling of failed CFRP products into non-reinforced composites. Simply shredding the residual waste makes it useable as a base material for these lower-grade composites.

The usage ATC in combination with other materials, as part of a subsystem, seems like the most realistic short to medium-term outcome for the OEM. Take for example the body-in-white (BIW), this structure can be made of several materials to enable a hybrid or multi-material construction. In current higher-end cars, this is often the case.

COMPATIBILITY

The compatibility of ATC is currently facing an unspecified amount of uncertainty to the OEM. According to this system integrator, ATC will find its way into body structures, but this process will take place step by step. Application segments deemed most suitable for current implementation are semi-structures and closures. Based on the OEMs experience with thermoplastic CFRP, which are deemed ´very expensive technology’, an application with ATC “must have a lot of advantages on the functional side”, as it is perceived to be equally as expensive.
Following the line of reasoning of the TIER, a lower uncertainty with regard to compatibility is perceived. Issues of note are the compatibility of joining ATC and other composites with incumbent materials is difficult yet not impossible. As the respondent puts it, “..joining techniques offer a challenge but in my opinion it is highly compatible. (..) by adding processing steps, gluing or bolting, nearly every problem finds its solution”. Past substitution experiences by the TIER include SMC (thermoset) composite that already have been implemented a lot.
The implementation of composite parts into existing mass production facilities seems to be one of the last problems of the seemingly long list of expected challenges for composites. The OEM foresees difficulties with the potential integration in existing factory ‘shop floor layouts’. The main issue here is that investments are needed in order to integrate ATC in current manufacturing processes. The alternative is “to go into different solutions which are not in serial production yet”.

COMPLEXITY

Understanding the behavior of ATC in the broad range of thermal requirements is one of the complexities stated by the OEM. The performance and other properties of ATC add to this complexity dimension. For the OEM it is

also needed that the ATC application is able to co-exist with other lightweight material systems. This remains an area of ongoing investigation.
Complexity is also acknowledged by the TIER. However, it reasons that "the adoption starts with acceptation and a healthy interest for this technology at the OEM. The eventual material 'clearance' leads to a positive adoption decision and now the material has to become implemented in the value chain". As the lack of credible suppliers and TIERs maintains, this lowers trust in ATC, leading to a slower implementation (adoption) process.

TRIALABILITY

Within the OEM, validation processes are in place before material innovations qualify to end up in cars. Full scale material qualification and testing processes are needed, "as with any new material or innovation". When informing about the duration of these processes, no comments are made.
TIER: Testing procedures of ATC is well possible, however it quickly evolves into a implementation issue (see complexity). Simulation and analysis can however prove to be more difficult in reality when different simulation software is used at the OEM organization which turns out to be not fully compatible with the TIER's software. This lack of available CAE software is also mentioned in another source (Baron & Modi, 2016), thus strengthening the argument of this problem.

OBSERVABILITY

According to the TIER, ATC is perceived to be a perfect material in theory, but in reality a lot of other materials can deliver a similar performance for, at this date, a far lower price point. "Making a carbon-dominant car is a strategic choice.. (..) performance wise, carbon is not always necessary". This also counts for future regulations, so the materials of a car are always expected to be multi-material solution. The OEM did not directly reflect on observability characteristics of ATC. However, in another publication of their own, the 'anchoring of CFRP in the public' was mentioned (Starke, 2016).

THIRD STAGE IDP: DECISION

The OEM currently has no realized application for ATC in current production and out of confidentiality issues, does not want to comment further on adoption decisions of projects in development. However, it repeated that the decision for a certain material is based on whether an innovative material like ATC is the right cofncept for the potential application about which adoption is being investigated. Starting small enables learning about these materials in series production. Understanding a material or mix of materials allows for combinations of CFRP with incumbent materials. This creates a learning-curve that enables larger BIW applications for higher volumes. Still, the trade-off between costs and performance, and amount of parts remains, which is "what basically leads the decision what the right material is."
The TIER has had experience with positive adoption decision of ATC for a seating application. However, this party was being forced by the OEM to work with their dedicated system supplier with Tier1 status. This now downgrade this TIERs position to that of supplying the T1, thus acting as T2, with no direct communication with the OEM. The result was a considerable slow-down in the adotion decision process (ADP).

The adoption decision of the OEM boils down to the strategy of the company. And even then, when materials are concerned, it is always the question of what advantage ATC brings that incumbent material solutions cannot. In order for ATC to be used in the body structure or to be the basis of the architecture (passenger cell) of a car, this will "probably take another 5 to 10 years". The process-chains that exist at the OEM site make sure that all decisions taken work together with the needed disciplines.

MENTIONED CONSTRAINTS FOR NON-ADOPTION DECISIONS

TYPE	CONSTRAINTS	OEM	TIER
	ECONOMIC CONSTRAINTS		
External	High material costs	X	X
Internal	Non-profitability of the new technology (working business case)	X	X
Internal	High switching costs	X	
	TECHNOLOGICAL CONSTRAINTS		
External	Lack of system-integration in the current design		X
External	Non-availability of supplier(s) that can meet the supply requirements	X	X
Both I/E	Complexity of thermoplastic composite technology	X	X
Both I/E	Lack of proper simulation tools to analyze structural application	X	X
	FEASIBILITY CONSTRAINTS		
Internal	Incompatibility of the new technology with the norms and customs of the local environment (shop floor layout)	X	
External	Lack of access and control over production resources (e.g. thermoplastic tailored blanks)		X
Internal	No direct need for ATC in current applications, unclear which problems are solved that other materials can	X	
External	As TIER1, forced to work as T2, no direct communication with OEM slowing down adoption of even stopping it		X

Table 1 Mentioned constraints for non-adoption decisions

The first constraint mentioned that seriously constrains adoption is the cost level of advanced thermoplastic composites. For structural applications, the raw materials needed are currently around 6 to 8 times more expensive than steel, and 3-4 times more expensive than aluminum. It has to be noted though that several industrial parties are working on this issue, trying to find ways for cheaper fiber construction, developing thermoplastic resins with lower costs or shorter processing times. Another cost lowering part can be the “lower amount of pieces needed” when a (structural) solution is developed with this technology. Due to better design freedom, parts or functions of different parts can be integrated in a single solution, lowering the amount of production steps and parts. This could partially offset the increase in material costs.

4.2 DISCUSSION OF FACTORS INFLUENCING THE ADOPTION-DECISION

After distinguishing the different constraints to the adoption-decision of ATC, it is now time to look at the underlying factors. By looking at these factors, the second part of the main question can be answered.

EXTERNAL FACTORS

Factors originating from an external source that are harder to influence are currently the price of raw materials and regulations. Developments regarding the lowering of fiber and resin prices have been and remain under development. These economic factors are expected to influence the buying behavior in a negative way, as the decision maker assumedly has a hard time in persuading his peers and/or the strategic DMU about the adoption decision at hand.

The hierarchical related factor (in feasibility) with multiple Tiers involved, is for an innovation-supplying Tier a difficult situation. Being forced to act as a part of the supplying structure of an OEM, having to work with the system supplier of that OEM, resembles a 'take it or leave it' approach. To avoid this situation is to almost certainly lose the opportunity for adopting and implementing a new material technology.

INTERNAL FACTORS

The available budget to start adopting and implementing ATC should be available. Due to high switching costs, material costs, this decision demands considerate dedication to this material, making it at this point in time, a strategic decision. Capability developments in the manufacturing department are needed to enable tproduction with these materials alongside incumbent materials. Also, proper implementating and development of technical designs is needed. This will allow for better performance/cost ratio's.

4.3 SECONDARY SOURCES OF AUTOMOTIVE ADOPTION

4.3.1 PREVIOUS MATERIAL ADOPTION CASES

In the automotive sector it is arguable that certain OEMs are more willing to adopt innovations , earlier than others. This also applies to the acceptance of new materials. The different models across the OEMs line-up however are far harder to generalize into a particular segment. It is often seen that an OEM starts a sub-brand to implement a certain new technology, e.g. BMW's i-range.

ALUMINUM

Aluminum has found its way into the mass-produced automotive value chain since the last decade. It is widely recognized as the best alternative to steel due to the emphasis on fuel economy, carbon footprint by both consumers and industry (Automotive megatrends, dec.2015). When looking at the design process, aluminum is very similar to steel. Issues that arose when implementing aluminum were combining this material with other metals. joining methods have since been developed and continue to develop, even after adoption has taken place. The material has proven to be scalable to the extent that it has enabled mass-produced cars with aluminum frames, and parts like fenders, hoods and roofs (Lotus, 2012, p232).

Whereas the material has become mainstream in the last decade, the adoption process has been going on for more than two decades. The introduction went into mass production in the middle of the '00s, and currently the percentage of aluminum applications is still increasing, at a slow rate (Ducker, 2012).

(A)HHS – (ADVANCED) HIGH STRENGTH STEEL

High-strength steel (HSS), be it advanced or ultra, are a relatively young set of steel grades that are strong and can reduce component weight by up to 25%, and total weight by an estimated 20%. This material does come at a higher cost than conventional steel grades. However, as it strength allows for less material used in the part or component, HSS is regarded as a cost-effective alternative for light weighting. The incumbent, steel-based manufacturing infrastructure also favors this material, as it requires little modification to current production processes. This has translated in a rapid adoption and implementation rate in cars like the Mercedes E class (Lotus, 2012, p233).

COMPOSITES

Although the start of composite materials usage by the automotive industry dates back from the '50s, there spread of this innovative material remains limited (Mangino et al, 2007). The word composite can cause unwanted 'noise' in the communication about this material. As defined by Merriam-Webster, a composite "..is made up of distinct parts (…) factorable in to two or more prime factors". This rather broad definition makes that technically any material composed of two or more parts is a composite. Here, the focus of this research is Advanced Thermoplastic (fiber reinforced) Composite (ATC) materials aimed at automotive application. As one interview pointed out, there are already several existing applications of non-structural, sometimes non-fiber reinforced applications of thermoplastic composite materials in cars. These 'lower tech' type of thermoplastic composites are already adopted as suitable alternatives to steel or aluminum materials, often based on a reduction in costs, parts needed or a combination of similar factors. In the higher segment of non-mass produced cars and in motorsport, thermoset carbon(fiber reinforced plastic) composites (CFRP) have proven to be a costly but very good replacement of other lightweight materials.

Factors that have enabled research into the applications of automotive composites are mainly related to its material properties (lightweight, high strength/stiffness, non-corrosive). Thermoplastic composites add to this an excellent processability, with short similar to steel processes. The main push towards automotive composites is predicted on the idea that reducing weight is a cost-efficient method for reducing fuel consumption. A rule of thumb in the automotive industry is that a 10% reduction in weight leads to 6-8% reduction in fuel consumption (Vicari, 2015). This is expected to result in vehicles to gradually become lighter as fuel economy standards are becoming stricter (see paragraph 2.3.2).

Factors that have thus far hindered widespread usage of automotive composites are primarily economical of nature. These 'constraints to innovation adoption' are the expensive raw materials (carbon fibers, resins) which are a lot more expensive than steel. In 2011, CFRP's were about 20 times more expensive. Also, high switching costs will occur as significant investments are needed when adopting this material as existing production lines need to be written off or need alteration. The composite material suppliers are therefore focusing on cost reductions and easy-to-process materials that will make it more compatible with current production standards. The other factors are of a more technical nature as there are several issues relating to the qualification, design and use of composite materials. These issues are accurate material characterization, manufacturing and joining with other materials (Mangino, 2007).

The future of ATC is therefore, uncertain as to whether it will become fully adopted in the mainstream, mass-produced car market. The following demands for a future with lightweight CFRP design are detected. Material costs are expected to decrease: developments in fiber and resin technology indicate that in the next decade, CFRP's, either thermoset or thermoplastic, will be more feasible from both technological and economic standpoint. Reduction of process costs (in relation with the correct design, are another demand for future design with CFRP. Developments of low-cost manufacturing methods for composites continues, with fewer process steps and more function integration will help here. Other areas for improvement deal with composite properties: simulation prediction and properties improvement such as selecting the right material and process. Finally, a safe and stable process will enable further weight reduction (Starke, 2016). The pursuit of these demands implies that the adoption process should start in the next years, or that this process is already on its way. It is however estimated that growth in composite materials for the BIW "will be seen as vehicles near the 10% or greater lightweight objective" (Baron & Modi, 2016). In essence, the lighter vehicles need to become, the more expensive this 'material pathway' becomes. By this discovery the potential success of ATC adoption becomes apparent.

The following table summarizes the barriers that hinder the adoption of ATC and other lightweight materials:

BARRIER	RANK
Capital investment	1
Manufacturing Capacity	2
Design	3
Material Qualification	4
Supplier Base Competitiveness	5

Table 2 Rank order of barriers from introducing lightweight materials (Baron & Modi, 2016)

The ranking is that the capital investment is the most challenging barrier to overcome, and the supplier base competitiveness is the least challenging.

4.3.2 LAWS AND REGULATIONS INFLUENCING THE ADOPTION OF ATC

In order to decarbonize the automotive industry, local governmental laws and regulations have been putting a tax surplus on polluting vehicles for decades. Either through fuel taxes or fiscal incentives, the efficiency of cars could be improved without stringent standards. This has behavior has been most visible in regions like Europe and Japan. As gradually the call for action to slow down climate change became more severe, both the European Union and the American senate have set very clear and demanding targets for OEMs. American standards focus on fuel economy and dictates rather stringent fuel standards, whereas EU rules focus on CO_2 emission reduction. The figure below shows the GHG emission rates in the main vehicle markets:

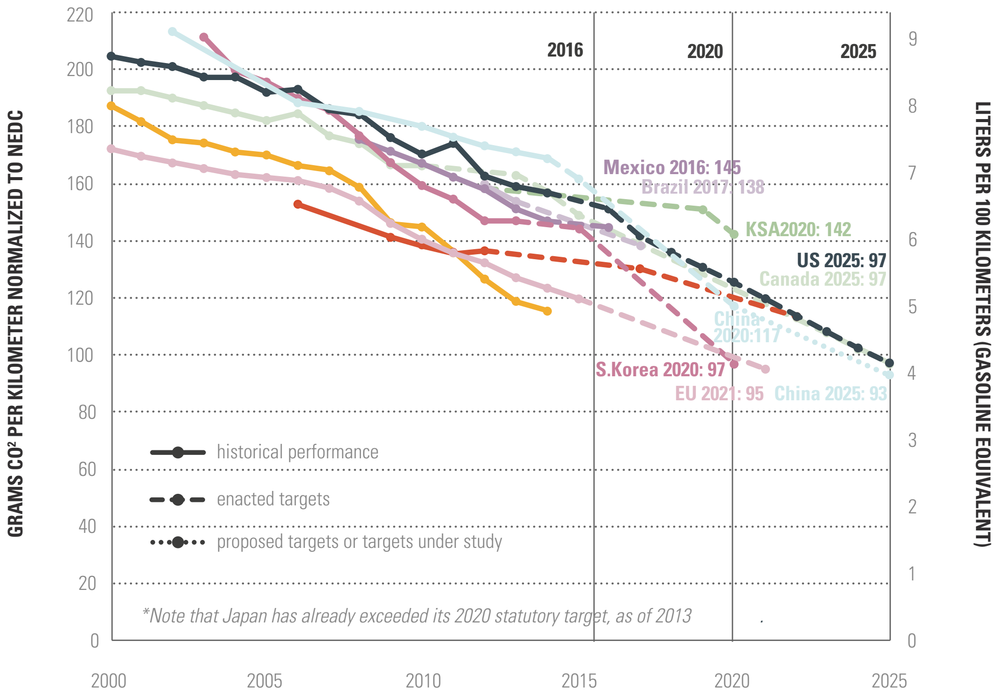


FIGURE 6 Comparison of global CO2 regulations for new passenger cars (ICCT, 2016)

Corporate Average Fuel Economy (CAFE) standards will require OEMs to achieve a fleet average of 35.5MPG by 2016, reduced to 54.5 MPG by 2025. The European Union sets restrictions on CO_2 emissions for passenger vehicles, starting at 130g CO_2 per KM today to 95g CO_2 /KM in 2020 (Diaz et al, 2016). To put things in perceptive, a CO_2 reduction of 10-15g/km can be achieved for each 100kg of weight reduced. When exceeding the stated emission limits, OEMs pay an excess emissions premium for each car registered (EC Climate Action) The Volkswagen scandal ('dieselgate') however has posed a challenge for the EU regulators. Where in the US, more compliance tests were added, the EU officials weakened their emissions standards in order to provide OEMs with more time to adjust to these newer standards (Klier & Linn, 2016). This example clearly demonstrates that rules and regulations regarding emissions remain dependent on time and/or situation, and therefore can be observed by the industry to remain 'fluid' to some extent until they have been definitively institutionalized. This also creates room for lobbyists to influence these standards.

Both CAFE and EU regulations focus on so-called 'tailpipe emissions', which are the emissions from usage of fossil fuels. While lightweight materials are capable of lowering this type of emissions (consumer phase in figure 7), the production emissions of a car with such materials can offset this emission advantage. Notably the steel industry is therefore a proponent of looking at the life cycle impact of both production (raw material, component phase, figure 7) and driving emissions, as steel-based materials tend to have comparably a lower energy-intensive production process. This could offset a lot of the potential emission savings made by having a lower weight composites-based car, or any 'multi-material' car for that matter (Worldautosteel, 2013).

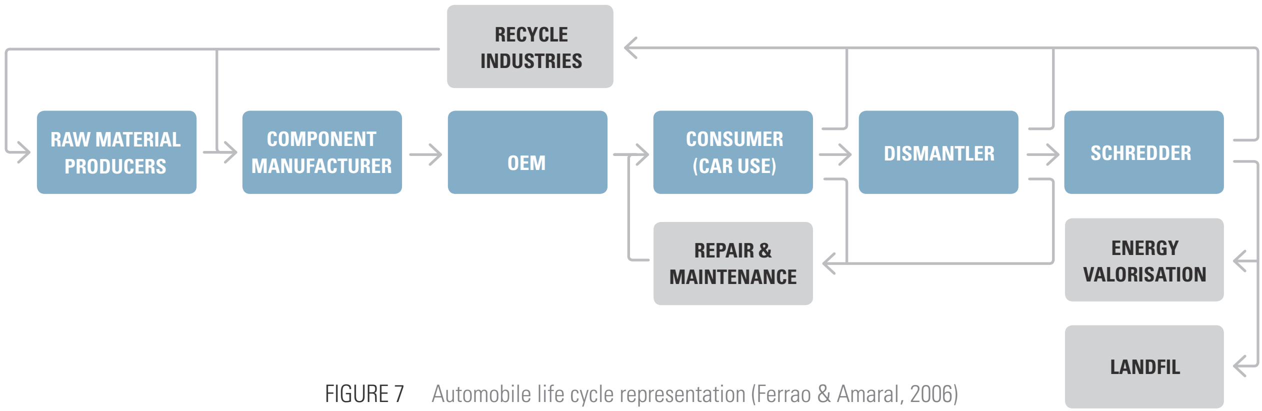


FIGURE 7 Automobile life cycle representation (Ferrao & Amaral, 2006)

Another type of regulation that influence the adoption are concerned with safety. An example of this is 'FMVSS/ IIHS' which contains key structural and impact requirements for materials used in car bodypanels. (Lotus 2012). However, a material that brings about better mechanical properties is with the current safety testing procedures not or hardly noticed.

4.3.3 SWOT ANALYSIS FOR ADVANCED THERMOPLASTIC COMPOSITES IN THE AUTOMOTIVE INDUSTRY

Based on the interview data, ownobservations at a materials supplier, and market literature, trade journals and other secondary sources the following SWOT analysis was developed. It will give a concise overview of the several aspects that directly influence this decision making. A small disclaimer is at its place as this analysis is however currently actual, time-dependent. As technology evolves, costs go down and especially when ATC becomes a material of choice for the automotive industry, these underlying aspects will be different. Currently, the situation is as following:

STRENGTHS

- Technological advantages that come along with thermoplastic composite technology: lightweight, strong, design freedom, enabling fast processing, indefinite shelf life for unprocessed parts, and function integration through overmolding
- Marketable advantages are associated with lower fuel consumption, safety (high impact resistance), enhanced handling, and chemical resistance (e.g. no more rust)

WEAKNESSES

- High initial investments needed: switching and sunk costs for TIERs/OEMs
- High prices for raw materials (e.g. carbon fibers, resins)
- Few suppliers currently available to supply high-quality ATC's, causing great dependency for buyers
- Uncertainty due to unfamiliarity in automotive with ATC as a mass-producible material
- Several technological challenges arise when combining thermoplastic composites with other, more conventional materials within existing designs
- To date, no production line exists that can deliver and showcase mass-produced ATC for automotive applications at compelling prices
-

OPPORTUNITIES

- Costs of raw materials (fibers and resins) are expected to drop in following years
- Rising oil prices and even more stringent (emission standards) rules and regulations are main causes for further 'light weighting' of the automotive sector
- Consumers demand cleaner and more fuel-efficient vehicles
- Processability of ATC improves even further, along with other properties that could contribute to the potential value added (such as better joining technologies with other lightweight materials)
- Recyclability of ATC should outperform thermoset composites (e.g. due to reshape ability)

THREATS

- Incumbent, generally more affordable and conventional materials with an approach that also allow for lightweight design possibilities: HSS, aluminum
- Thermoset composites, especially developments shortening its production process, could eventually make this the go-to composite technology for coming years
- Material production emissions and/or end-of-cycle phases could prove to be not as environmentally friendly as assumed (see also recyclability)

4.4 FINDINGS ROUND-UP

The ultimate dependent variable was the rate of adoption (of ATC). The analysis was on organizational population level, with the type of organization being manufacturing organizations with a clear profit orientation. The types of innovation were of a clear technical nature. Given the extent to which ATC changes the product and the process of the automotive industry, this is observed as an incremental innovation. As the nature of the finalized product is not directly affected by the adoption of ATC, whereas the production process is influenced to a great extent, this can also be described as a process innovation case. A small note should be made, that the case study of ATC adoption on its own is not ground breaking enough to be perceived as a part of radical innovation. However, in combination with other automotive innovations like an electrified powertrain, together this can very well be

perceived as a more radical product innovation as this can create a new product category.
The scope of innovation was based on the single innovation of ATC, which has the potential to become a multiple innovation case as reinvention is likely to occur after adoption success has occurred. This is depending on application. In this research, scope was therefore based on this single innovation case study. Although multiple innovation adoptions are already in process or implemented by the automotive OEMs and TIERs, it could be argued that this positively influences the willingness to adopt an innovation is higher, leading to greater propensity to adopt an innovation.

Having a look at the different buyer roles involved; the users of ATC in automotive applications would be the design engineers and production employees executing the so-called 'shop floor activities'. The users were, according to the interviews, not that prominently influencing the adoption (and buying process, for that matter), as their main link to the adoption decision would mainly become apparent in the implementation phase, just after the adoption decision.
The influencers were identified most prominently at the TIER organization, where the decision to adopt or buy ATC was aided by their extensive experience with thermoplastic composites. The 'modus operandus' of this buyer role was to influence the process by the proposal of applications made from ATC, as well as reducing uncertainty by trying to provide information regarding the application at hand. Within the OEM organization, although it is likely that there are influencers around, the role of influencers were explicitly mentioned.
The deciders with authority to make to choose from alternative materials, were most active at the OEM site. Their view on the strategic choice for ATC adoption indicates that if their perception would become more favorable, this material could be chosen above other alternatives.
The buyers currently have a lot to complain about the economic factors not favoring ATC from price point of view. This is likely postponing any buying actions from their account.

The material substitution parameters technical performance advantage and environmental and legislative considerations appeared to be favoring substitution of incumbent materials by ATC. The trade-off is however, that with current cost-levels on both material as well as production side, the economic advantage parameter needs further development. The product character change remained an unmentioned factor by both the TIER and the OEM. This is in line with a low observability of the

The perceived characteristics of ATC were discussed extensively in previous paragraphs. Most notably, compatibility, complexity, trialability appeared to be having great influence on the current slow adoption rate. Compatibility, although not perceived by the TIER as a particulary influencing constraint, the lack of compatibility was from OEM perspective rather large, therefore only gradual progress with ATC adoption could be expected. Trialability
The perceived complexity of ATC remains an area that needs further improvement as both the TIER and OEM are looking at the need for the ability of ATC applications that can co-exist in system solutions with other lightweight materials.

Understanding the behavior of ATC in the broad range of thermal requirements is one of the complexities stated by the OEM. The performance and other properties of ATC add to this complexity dimension. For the OEM it is also needed that the ATC application is able to co-exist with other lightweight material systems. This remains an area of ongoing investigation.
Complexity is also acknowledged by the TIER. However, it reasons that "the adoption starts with acceptation and a healthy interest for this technology at the OEM. The eventual material 'clearance' leads to a positive adoption

decision and now the material has to become implemented in the value chain". As the lack of credible suppliers and TIERs maintains, this lowers trust in ATC, leading to a slower implementation (adoption) process.

Observability of ATC needs to be improved as the choice for ATC in the design currently is regarded as a strategic choice. The end-user needs further 'priming' with composites as well, according to the OEM.

Advanced Thermoplastic Composite materials are often seen as a lightweight material able to replace incumbent materials. However, integrating these materials into production lines proves to be difficult, and also design, simulation, challenges will appear. Currently detected barriers are preventing mainstream usage are material costs and issues with forming, joining and the supply of materials. Also, manufacturing capacity is not existing at this point in time. As a result, the use of composites in structural applications are expected to remain limited in the near future. However, as the technology of ATC develops, the cost levels are expected to drop significantly. Once ATC becomes adopted, experience with this material will create learning effects. In combination with an available production line, this could become a cause for derived demand in the sense that other applications with ATC can now be realized easier and probably a lot quicker. This however is a theoretical argument, it remains to be seen if certain applications do make sense from technological point of view. Another cause for derived demand of ATC can be found in the existing applications of thermoset composites. In such instance, familiarity with composites is present in areas such as design and technology implementation, which will act as a cause for better propensity to substitution with ATC. This can happen with an application with thermoset needs to be extended with an ´add-on' application better suitable for ATC.

To answer the second part of the research question; how can these constraints be solved or neutralized?
By starting from the detected constraints, the focus needs to shift to future possibilities with ATC. Based on certain conditions, such as the feasibility of ATC applications, more adoption and implementation decisions can be expected to be made.

The main reason for the current low rate of adoption lies in the persuasion stage of the IDP. In short, the perceived characteristics of ATC should be positive enough to create an adoption favoring decision. Furthermore, the regulations factors remains more of a black box, although it is rather certain that the environmental standards are likely to become only tighter than current standards.

In order to use the full potential of the substitution material, a full redesign of the component is needed This rather thorough approach leaves no room for failure, which puts a lot of pressure on the adoption decision as ideally, all characteristics of ATC and the component design should be fully understood before committing to such a decision. It is therefore is assumed that to have the adoption of advanced thermoplastic composites in structural applications succeed, all stages of the automotive value chain need to be involved in this effort.

Derived demand is expected to start to occur mainly after the first adoption decisions have proven to be a success. This substitution process goes hand in hand with the projected decline in cost levels due to technological developments made in this area.

Given the attributes of ATC as an innovation, its adoption decision apparently seems to pose more difficulties to the system integrator (OEM) than it does to the supplier (TIER). It is therefore a strategic decision to adopt (or reject) ATC for an OEM. Furthermore, to make full use of the material properties ATC technology provides, it is necessary to have clearly defined applications where this material can outperform incumbent materials. Function integration can, to a certain extent, offset the higher price point of ATC.

Advanced thermoplastic composites will most likely create value for the TIERs/OEMs when starting with all stakeholders involved in an (the) early(est) design stage (possible). This enables the definition of all requirements and desires, again aiding function integration by the application at hand. The usage of ATC adds value to both the OEM/TIER and the end-user when relative advantage is obtained by a significant reduction of the total weight in combination with cost control of raw materials and manufacturing.

Now that the factors to overcome the constraints are detected, it remains difficult, at this point in the ADP, to exactly state which factor or factors are the most important and therefore have the highest priority.

CHAPTER 5. CONCLUSION & RECOMMENDATIONS

"The main conclusions are listed followed by recommendations for the materials supplier. Also, limitations and opportunities for further research are stated, finalizing the thesis with some thoughts about contribution to literature and reflection."

5. CONCLUSION & RECOMMENDATIONS

In this final chapter, the main conclusions will be stated as based on the finding as found in the semi-structural interviews and secondary sources. To build on these conclusions, several recommendations are presented with the position of an ATC supplying organization in mind. The limitations and further research opportunities are also part of the chapter, as there are many ways this thesis could serve as a basis for other research into (automotive) adoption decisions. The contributions by and reflection on this research project completes this chapter.

5.1 CONCLUSION

A new material innovation such as ATC faces a number of challenges during its adoption. In addition to determining how to encourage adoption (through persuasion?), suppliers of ATC can also be challenged by the reluctance of automotive OEMs to accept this material. Persuading OEMs to adopt the material first requires demonstrating trialability and observability restrictions to be taken away.

Economical constraints were found to be the most challenging. The capital investment needed is high, and are base materials are costly. The result of these conditions was often mentioned as “to have a working the business-case”, meaning that the decision to adopt would only be made if the payoff in terms of problem solving would be perceived to be higher than the costs involved. In order to make this analysis, the entire production concept must be taken into consideration. This is because of the relatively costly base material and capital investments needed. The benefit obtainable need to offset the additional expenses on raw materials and production. The adoption of ATC’s on mass-production level requires a large initial capital investment into production lines. Luckily, rules and regulations are pushing towards further lightweighting of the automotive industry. As the targets for weight reduction go up, so do the costs involved. In comparison, developments with ATC indicate that there is room for cost savings. These two trends, the higher weight saving targets and lower cost ATC are bound to break even in the future.

The technological constraints and the feasibility constraints express a clear concern regarding the lack of a proven production line for mass-produced ATC parts or chassis implementations. A low number of suitable TIERs and/or material suppliers further dents the trust in a feasible solution. This lack of a ’robust supply base’ was also observed in another research (Baron & Modi, 2016). A pilot line showcasing a production system or parts of that system, would be able to lower some of this envisioned uncertainty. By providing a proof-of-concept, this demonstrates both the product and the process properties of ATC. A more elaborated explanation follows in the next paragraph.

To finally conclude, the focus of this thesis on thermoplastic CFRP was mainly incentivized by the material supplier that gave the starting situation for this research. Thermoset composites were stated as less suitable for the fast, high production process in the automotive industry. In practice, thermoset and thermoplastic technologies are both material systems with a lot of application potential for the high-performance applications. Technology developments in thermoplastic and thermoset technology are constantly ongoing. Based on interviews and personal observations, both technologies can co-exist in the automotive industry, and the ongoing competition between the two systems will lead to advanced composites becoming overall a better substitute for incumbent materials.

5.2 RECOMMENDATIONS TO POSITIVELY INFLUENCE THE ADOPTON DECISION

In order to enable the adoption and diffusion of ATC, two recommendations were developed.

Firstly, the material supplier should invest in a pilot production line, allowing OEMs and TIERs to see the possibilities with ATC. This test line will function as a proof-of-concept, making the perceived observability far clearer as this allows for a better perception of the possibilities associated with ATC adoption. Trialability will be positively influenced as well, since a pilot line will enable for easier testing and allow to further optimize the manufacturing process to enable high volume production. It is reasonable to assume that by experimenting with this pilot line, manufacturing know-how related to these high-volume numbers will be developed more in-depth, perfecting manufacturing techniques as well as being able to estimate and accordingly design the own production process of the ATC manufacturer so that it becomes compatible with the demanding automotive industry.

Secondly, licensing partnerships to facilitate the technology transfer of ATC is another way to create more business with ATC. As seen with the Tessera case (Shih, 2010; Hedberg et al, 2009), which describes an example from practice in the electronics industry, it is not always about actual production with the technology at hand. There is a clear need to demonstrate the technology and producibility. Therefore, product technology licensing is a viable option for a supplying organization with patents and trademarked IP. This enables a revenue stream other than the existing way of material production that is sold to industrial buyers. By focusing on potential customers who have a perceived need for lightweighting in automotive industry, the change in strategy will become apparent. This approach could work twofold: first, the rate of adoption of ATC could be improved as other OEMs or TIERs can use and experiment with ATC technology, setting up manufacturing capabilities, thus making it a more acceptable substitute. Of course, all in close cooperation with the material supplier. Second, with each extra licensing project, the costs involved for the supplier will be lower, leading towards a situation in which the initial investments for a pilot line could become a lot more bearable. A return on investment on the innovations related to ATC technology as well as manufacturability can be expected. The

In conclusion, the current situation with ATC resembles a chicken and egg situation; the current demand for ATC stated by the automotive industry is low. The lack of a proper production facility capable of processing ATC at the high-volume level necessary by the automotive industry is not enabling further demand. From the materials supplier perspective, the marketplace needs to be developed. Logically, joint development projects with either TIER or OEM organizations seemed be the way forward, however this approach did not generate any success in the last few years. To persuade the automotive industry to adopt ATC technology, the supplier needs another business model. Also, application development for specific automotive solutions is needed to get the adoption on its way. This lead to the recommendation that a pilot production line is needed, as well as licensing partnerships.

5.3 LIMITATIONS OF THIS RESEARCH

Due to the low amount of different interview sources, the degree by which this research is applicable to other segments of the automotive industry, or other industries adopting ATC, remains limited. For better generalizability, more respondents from different OEMs or TIERs would be needed.

As experienced throughout the data collection phase of this research, access to OEMs and TIERs was a difficult barrier to cross. Even if access was granted, companies remained on their qui-vive to make sure no sensitive information was shared. If another research in the same industry regarding innovation adoption were to be executed, it would be highly recommended to first have proper access to these organizations.

5.4 OPPORTUNITIES FOR FURTHER RESEARCH

Firstly, a research with a more quantitative focus would be a viable option as it will enable to look at the specific roles of the perceived innovation characteristics in the innovation decision process (IDP). The current approach in this thesis remains to use rather general concepts related to these characteristics, resulting in a somewhat fuzzy image of the roles involved.

Secondly, due to the current stage in the adoption process, it would be very interesting to execute a similar research again in the next five to ten years. By then, it would have become clearly visible if ATC or advanced composites in general were indeed the automotive lightweight material suitable for mass production, exposing the underlying factors that eventually sped up the adoption process. Or, if non-adoption or implementation remained at a similar rate, by then the constraints will developed as well to become even clearer than in the current situation. After successful adoption and implementation decisions, the second part of the DOI process could also become an interesting topic, as this was no part of this research. This research could follow the same qualitative approach as used in this thesis.

Thirdly, the scope of innovation of this research was rather low, as it was focusing on one innovation adoption. Single innovation studies tend to ignore the fact that organizations, especially large ones, adopt many innovations in a given time period. Results of those studies may reflect the attributes of the innovations studied more than the characteristics of the organizations. When multiple innovations are studied, the influence of innovation attributes decreases. When all innovations adopted are considered, the role of organizational characteristics becomes more evident. Multiple innovation studies are also needed because identification of the characteristics that facilitate innovation adoption are necessary in the design and management of innovative organizations. Many studies of organizational innovation have measured innovativeness by the number of innovations adopted in a given time period. Therefore, determinants of innovation and the strength of their influence depend on whether or not a comprehensive group of innovations related to various parts of an organization is studied.

5.5 CONTRIBUTIONS AND REFLECTION

By finalizing this research, the author hopes to have added a small contribution to the large body of knowledge in business administrative context. More specifically, the aim to add knowledge about adoption and diffusion in a specific industry, adoption constraints and influencing factors were discovered that previously remained less clear. By considering workarounds for these constraining factors, this lead to a different view on how this particular adoption process could be approached.

The process of undertaking this research was at times a real test of commitment. A lot that could go wrong, seemed to go wrong at some point in time. The focus of the research was not very clearly defined at the start, leading to several iterations. Data analysis without proper access proved to be a major factor limiting the data gathering phase. However, in the end, these issues were solved to a satisfying extent, resulting in this finalized thesis. Analyzing the process of adoption of an innovation from different perspectives whilst still in progress, helped in gaining a lot of insights in the way the automotive industry is set to deal with innovations and manufacturing in general.

CHAPTER 6.
BIBLIOGRAPHY

6. BIBLIOGRAPHY

6.1 SCIENTIFIC LITERATURE

Beardmore, P., Johnson, C.F. (1986). The Potential for Composites in Structural Automotive Applications. Composites Science and Technology, Vol26, 251-281

Damanpour, F. (1991). Organizational Innovation: A Meta-Analysis of Effects of Determinants and Moderators. The Academy of Management Journal, Vol34 No3

Elbertsen, L., Van Reekum, R. (2008). To ERP or not to ERP? Factors influencing the adoption decision. International Journal of Management and Enterprise Development, Vol5 No3

Farag, M.M. (2008). Quantitative methods of materials substitution: application to automotive components. Materials and Design 29, 374-380

Ferrao P., Amaral, J. (2006). Assessing the economics of auto recycling activities in relation to European Union Directive on end of life vehicles. Technological Forecasting & Social change, No 73, 277-289

Grant, R.M. (2010). Contemporary strategy analysis. Wiley & Sons, 7th edition

Hedberg, C., Kerns, D., Carlson, J. (2009). Tessera. Babson & Ohlin College

Mangino, E., Carruthers, J., Pitarresi, G. (2007). The future use of structural composite materials in the automotive industry. International Journal of Vehicle Design, No44

Möller, K.E. (1985). Research Strategies in Analyzing the Organizational Buying Process. Journal of Business Research, Vol 13, 3-17

Niciosa, F.M., Wind, Y (1977). Emerging Models of Organizational Buying Processes. Industrial Marketing Management, Vol 6, 353-369

Olshavsky & Spreng, (1996). An Exploratory Study of the Innovation Evaluation Process. Journal of Product Innovation Management, Vol13,512-529.

Porter, M.E. (2008). The Five Competitive Forces That Shape Strategy. Harvard Business Review

Pijpers, G.G.M., Bemelmans, T.M.A., Heemstra, F.J., Van Montfort, K.A.G.M. (2001). Senior executives' use of information technology. Information and Software Technology, Vol43, 959-971

Risthaus, M. (2012). How to Realize Lightweight Design in Mass Production. International Conference & Exhibition on Thermoplastic Composites, Bremen, Germany

Rogers, E.M. (2003). Diffusion of Innovations. Free Press, New York, Fifth Edition

Saunders, M.N.K, Lewis, P. Thornhill,A. (2009). Research methods for business students. Prentice Hall, Fifth edition.

Schulze, A., MacDuffie, J.P., Taube, F.A. (2015). Introduction: knowledge generation and innovation diffusion in the global automotive industry – change and stability during turbulent times. Industrial and Corporate Change, Vol 24, No 3, 603-611

Shih, W. (2010). Carrot or Stick? Getting Paid for Innovation at Tessera Technologies. Harvard Business School Publishing, Boston.

Straub, E.T. (2009). Understanding Technology Adoption: Theory and Future Directions for Informal Learning. Review of Educational Research, Vol 79, No 2., 625-649

Tornatzky, L.G., Klein, K.J. (1982). Innovation Characteristics and Innovation Adoption-Implementaiton: A Meta-Analysis of Findings. IEEE Transactions on Engineering Management, Vol 29 No1

Verschuren, P. & Doorweraard, H. (2007). Het ontwerpen van een onderzoek. Lemma, The Hague, 4th edition

Webster, F.E., Wind, Y. (1972). A General Model for Understanding Organizational Buying Behavior. Journal of Marketing, Vol36

6.2 NON-SCIENTIFIC LITERATURE

Baron, J.S., Modi, S. (2016). Assessing the Fleet-wide Material Technology and Costs to Lightweight Vehicles. CAR Center for Automotive Research, Ann Arbor

Bernhart, W., Dressler, N., Toth, A. (2010). Mastering Engineering Service Outsourcing in the automotive industry. Roland Berger strategy consultants, Market study No3/2010

Diaz, S., Tietge, U., Mock, P. (2016). CO2 emissions from new passenger cars in the EU: Car manufacturer's performance in 2015. The International Council on Clean Transportation, Briefing June 2016

Ducker Worldwide, authors unknown (2012). EAA Aluminum penetration in cars. Ducker worldwide LLC, Final Report, March 13 2012.

Klier, T., Linn, J. Comparing US and EU Approaches to Regulating Automotive Emissions and Fuel Economy. Resources for the future, april 2016.

Lotus engineering inc., authors unknown (2012). Evaluating the Structure and Crashworthiness of a 2020 Model-Year, Mass-Reduced Crossover Vehicle using FEA modeling. California Air Resources Board (CARB).

Starke, J. (2016). Carbon Composites in automotive structural applications. Presentation for EuCIA: Composites and Sustainability, Brussels

Stock, A., Egger, P. (2011). Organobleche verlassen das Hochpreissegment. Composites World, 12-17

Wyman report (2013). Trends, opportunities and solutons along the entire value chain.

6.3 URL'S

1 Reducing CO2 emissions from passenger cars, European Commission.
Retrieved from http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm on 12-08-2016

2 Super Light-weight Car Research and Development, WorldAutoSteel.
Retrieved from http://www.azom.com/article.aspx?ArticleID=9249 on 14-08-2016

3 What are prepregs, About Composites\
Retrieved from http://composite.about.com/od/eqptprepreggers/a/What-Are-Prepregs.htm on 20-11-2016

4 Vicari 2015. Will Carbon Fiber Find Widespread Use in the Automotive industry?, Machine Design
Retrieved from http://machinedesign.com/contributing-technical-experts/will-carbon-fiber-find-widespread-use-automotive-industry on 16-8-2016

5 Reinforced Thermoplastics: LFRT vs. GMT, Composites World
Retrieved from http://www.compositesworld.com/articles/reinforced-thermoplastics-lfrt-vs-gmt on 16-8-2016

6 Thermoplastic Composites: An Introduction, AZOM
Retrieved from http://www.azom.com/article.aspx?ArticleID=85 on 12-4-2016

7 Light Weight Reinforced Thermoplastic, Cannon Ergos
Retrieved from http://www.cannonergos.com/en/technologies/composite-processing/LWRT.html# on 16-8-2016

APPENDIX

A. Interview protocol

B. Background Advanced Thermoplastic Composites

A. INTERVIEW PROTOCOL

INTRODUCTION

Start with a general explanation of the research: The application of thermoplastic composites in the high-volume automotive industry remains to be an area where research projects or trials outnumber the actual realized applications. It is therefore an interesting goal to find out which factors constrain or enable the decision to adopt automotive thermoplastic composites.

By usage of open-ended questions, the interviewer aims to find out how the adoption decision-making processes for automotive thermoplastic composites take place in your organization. An interview is expected to have a duration of 60-90 minutes.

The words 'innovation' or 'technology' as stated in some of the questions, are meant as a shorter replacement for 'the technology adoption of advanced thermoplastic composites'.

Thank participants in advance for their time and effort.

1. BACKGROUND QUESTIONS

Could you briefly describe your background and your professional environment?

The initial questions are based on the Innovation Decision process (see figure 4).

2. PRIOR CONDITIONS

Previous practice/felt needs,problems/ norms of the social systems

1. Which needs (or problems) are potentially solved by the usage of advanced thermoplastic composites?
2. How would you describe the influence of the organizational environment on the adoption decision?
    a. What is the influence of competing firms?
    b. How about the input from supplying (TIER) organizations?

3. KNOWLEDGE STAGE

Gaining understanding of the (existence and) the functioning of the innovation

3. How do you perceive the communication behavior of (potential) innovation suppliers about this innovation?

Characteristics of the DMU

  a. Could you describe the communication behavior in your internal Decision Making Unit (DMU) about this innovation?
  b. According to your professional opinion, has all the above-mentioned communication lead to a mutual understanding of the difficulties of this innovation adoption?

4. PERSUASION STAGE

How is your attitude towards the innovation?

4. How do you perceive the relative advantage of thermoplastic composites? (or; which characteristics make thermoplastic composites a better material than aluminum/steel/smart steel?) (e.g. lighter than existing materials, more design-freedom, fast processability) DI-characteristic: Relative Advantage
5. How do you regard the compatibility of thermoplastic composites in the automotive materials mix? (or; how does the innovation match your needs, experiences and views?)
    a. Do you perceive the innovation as consistent with your needs as a (potential) adopter?
    b. How consistent is the innovation with past substitution experiences?
       (E.g. lessons learned from innovations such as aluminum, smart steel, thermoset composites)
    c. Which application segments are most suitable for implementation of thermoplastic composites? (segments e.g. chassis/exterior/

interior/engine&drivetrain/suspension/wheels) DI-characteristic: Compatibility

6. What is your opinion on the complexity of thermoplastic composites?
   a. Is the innovation difficult to understand and use?
   b. Could you elaborate on the difficulty of implementing this material in the automotive value chain? DI-characteristic: Complexity
7. Could you elaborate on the degree of experimentation before committing to adoption of this innovation? DI-characteristic: Trialability
8. What is your opinion on the visibility of the results of implementing this innovation? DI-characteristic: Observability
9. How is your attitude towards thermoplastic composites?
   (Control question with regard to earlier asked perceptions of Relative Advantage and Complexity (needs, experiences and views)).

5. DECISION STAGE

10. Why do you choose to (not) adopt/reject this technology at this moment?
    (Constraints of adoption: e.g. high material costs, complexity of TC)
11. When adopting: which factors were most important in this decision?
12. When rejecting: which factors do you perceive to constrain the innovation adoption?
    a. Which application segments were actively rejected?
    b. How do you perceive the option(s) for later adoption?
    c. Looking ahead, how do you expect these constraints to adoption be solved or neutralized in the future?
       (Control question with regard to factors mentioned at questions 6, 9 and 10. Compare answers and dig deeper into possible different factors or constraints mentioned.)

6. CONCLUDING

13. Are there any relevant topics left that you would like to discuss?

B. BACKGROUND ADVANCED THERMOPLASTIC COMPOSITES

Advanced Thermoplastic Composites, or ATC in short, is the focus material of this thesis. ´Advanced´ here stands for the continuous reinforcement of the composite that allow for application in critical, load bearing areas, e.g. crash beams. ´Thermoplastic´ indicates that the material can be shaped by melting and then pressing it in the desired shape. ´Composite´ means that the material is composed out of two materials, in this case of fibers (carbon, aramid, and/or specific types of glass fibers) in combination with a thermoplastic resin or melt-reprocessable 'matrix'. Thermoplastic polymer resins on their own are quite common in everyday life. PET or PVC are examples made of thermoplastic resins. These types of resins are unreinforced, and products are formed by pressing it into shapes[1].
Another category of thermoplastic composites are Glass-Mat thermoplastic (GMT) composites as found in the '86 Corvette and Long Fiber (-Reinforced) thermoplastic (LF(R)T), developed in the late nineties [2,3]. LWRT or LightWeight Reinforced Thermoplastics are a category of advanced GMT composites combining glass mats with textile reinforcements. LWRT is a popular material of choice for underbody panels, trim panels etcetera[4]

Most reinforced composites used in automotive to date are Carbon-fiber reinforced plastic (CFRP), where carbon fibers are put into a thermoset epoxy. Thermoplastic resins used in CFRP, are called Carbon Fiber Reinforced Thermoplastic composites (CFRTP composites).

The main properties of ATC that make it favorable above conventional thermoset composites are an increased impact resistance and reformability. The latter property enables faster processing, especially when dealing with thermoplastic prepregs (pre-impregnated composite/FRP).

1 http://composite.about.com/od/aboutcompositesplastics/a/Thermoplastic-Vs-Thermoset-Resins.htm#

2 http://www.compositesworld.com/articles/reinforced-thermoplastics-lfrt-vs-gmt

3 http://www.azom.com/article.aspx?ArticleID=85

4 http://www.cannonergos.com/en/technologies/composite-processing/LWRT.html#