Professional MBA
Automotive Industry

Big Data as Enabler for Customer-Oriented Automotive Development

A Master's Thesis submitted for the degree of
“Master of Business Administration”

supervised by
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Vienna, 29.09.2018

Affidavit

I, **DR. FABIAN EHRICH, BSC, MSC**, hereby declare

1. that I am the sole author of the present Master’s Thesis, "BIG DATA AS ENABLER FOR CUSTOMER-ORIENTED AUTOMOTIVE DEVELOPMENT", 110 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

In automotive development, there are lots of assumptions made regarding customer needs as well as customer usage of a car. With the introduction of interconnected vehicles, a transfer of data from customers' cars to automotive manufacturers will be possible. Access to data from sensors already embedded into the vehicle's system can give automakers an insight into customer behaviour and enables them to use this information in their development of new generations of vehicles. When applying appropriate big data analysis tools access to the vast amount of data produced with customer vehicles could help to replace existing development standards, which include various assumptions regarding customer use with requirements based on data analysis.

Privacy considerations are a very sensitive topic when it comes to analysing data from customer vehicles. While legal barriers regarding the use of personal data of customers are hardly existent in the US, the European Union has recently introduced strict rules, which regulate the collection and handling of customer data. At the same time, studies show that customers seem not too concerned about sharing their data with corporations they consider trustworthy. Thus, while legal frameworks have to be considered, data privacy seems no major road block for the introduction of analytic tools for data from customer cars.

In this study, the potential of using data from customer vehicles as input in different development departments of a car manufacturer is studied. Based on publicly available literature and a series of expert interviews with nine automotive professionals, several use-cases were formulated for which analysing customer data can help to pursue a more customer-oriented development. Seven groups of possible use-cases were established and evaluated regarding their potential benefits. All of the applications can offer significant cost saving potential for OEMs and enable the development of vehicles with additional customer benefit.

The necessary preconditions as well as the consequences of using customer data as input for automotive development are discussed in more detail in a case study with focus on an OEM's durability department. For this example, a more technical discussion regarding implementation and execution of a system for feeding data from customer vehicles into a development department is showcased.

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1 Introduction

Over the years, automakers have gained a vast base of experience in very different aspects of vehicle design and development. This experience in automotive research and development (R&D) departments is typically the foundation for the development of the next generation of cars. Most requirements, whether on a component level or for complete vehicles, are based on experience of predecessor projects, customer surveys, industry standards or studying competitor products. Thus, every new car generation is an evolution of previous models implementing new features, avoiding past mistakes and ensuring an increasing level of quality. However, this kind of evolutionary process inhibits the development of completely new concepts and is inoperative in times of disruptive changes due to introduction of by new technologies. In their current quality assurance processes, original equipment manufacturers (OEM) might find shortcomings in their products through customer surveys or quality checks. However, it is difficult to find areas where effort can be reduced without the risk of developing inadequate vehicles causing significant customer dissatisfaction. If new technologies advance quickly, OEMs will not have the experience base they have with well-known technologies which will make developments costlier and increases the risk of inadequate validation and consequently a higher exposure to releasing insufficient designs.

Cars of today have numerous electronic control units (ECU) which process a vast amount of data in every second of vehicle operation. Until recently, these data were collected, evaluated and processed in situ in the car but were not used otherwise. However, with the ability of next generation cars to communicate with OEMs via mobile data networks, these data could also be transferred from the vehicle to the car manufacturer. The sheer volume of resulting data can pile up very quickly and meaningful results can only be achieved when applying specialized big data analysis techniques. However, if applying the right methods, using this enormous pool of information can help OEMs to improve their habitual development procedure in different aspects. Using customer data as input for the development of future cars, automakers will be able to lower costs by reducing requirements where possible and increase profits by lifting restrictions of product range or options in certain markets. Furthermore, a better understanding of customer usage will give OEMs the chance to offer products with real customer benefit by developing features which are actually used and by leaving out unutilized attributes. Thus, manufacturers could increase their market share and simultaneously reduce their development and production costs. Finally, in a situation of radical technological change, as experienced in the automotive industry right now, the value of experience from the past is dwindling and not applicable to the latest technological advancements. In this case, direct feedback through transferring user data can help developing new technological capabilities within OEMs' development departments more quickly.

1.1 Automotive Development Process

Traditionally the automotive industry has been very hardware focused and only recently the focus towards digital customer experience has gained momentum. However, value creation in the automotive industry will gradually shift from hardware-driven to software-governed and soon the car is expected to be transformed into a "computer on wheels" (Bertoncello *et al.* 2016).

Over many decades, new generations of cars have been developed based on existing technology. Progress and refinement were developed in an evolutionary manner over several generations of vehicles. While in the first half of the 20th century most development incentives came from within the R&D departments, in the 1980s the market became a more important source of new ideas (Rothwell 1994). However, as already Henry Ford expressed with his famous quote "If I had asked people what they wanted, they would have said faster horses", this is no guarantee for revolutionary ideas but mostly a directional decision regarding existing technology. Today, landmark decisions regarding the positioning and fundamental requirements of a new vehicle project are based on various inputs. Typically, a new model is evaluated against its predecessor and competitor vehicles. This data set is the basis for a subsequent particularisation along the first development steps incorporating inputs from customer surveys, internal research programs or industry comparison studies as well as requests from the sales department. After a detailed description of the project on a level of the complete vehicle is finished, the requirements are broken down into functional groups and components, which then are developed within the corresponding developing departments. In an early stage of the component development first testing starts to verify each components' capabilities before integration tests and complete vehicle tests start. All these testing procedures are based on industry standards or experience gained over the previous decades of developing cars. While in certain fields different OEMs work together to develop test standards to ensure a homogeneous state-of-the-art among the industry (for example within VDA workshops), this procedure can be seen as a legal limbo regarding antitrust law (Gerster 2017). Internal company test standards are typically derived from lessons learned in previous developments. These can include experience gained during development or insights from quality issues (Yadav & Goel 2008). Learning from previous models to avoid the same quality issues ensures an increasing level of safety and quality (Mezger 2008). However, having no corrective from the market there is a trend regarding over-engineered solutions. Without risking quality issues and consequential pricy call-backs, this leads to an uncertainty which has the potential to increase the cost of a car substantially above the level needed for a safe and reliable usage. With increasing importance of software the automotive industry will experience a disruptive change from a hardware-driven to a software-dominated industry within the next decade (Weber & Weisbrod 2002, Riasanow *et al.* 2017). Thus, car manufacturers have to implement structural changes within their companies to develop new fields of expertise and prepare themselves for the technological changes ahead. Additionally, OEMs should question their current mode of operation and ask themselves how new technologies can help to improve their internal processes.

A typical model to describe the different stages of an automotive development process is the V-Model (see Fig. 1). While the x-axis denotes the timeline from project start until SOP (start of production) the y-axis represents the level of integration from a level representing the entire vehicle down to individual components. The left side of the V comprises definition and design tasks with increasing detail along the way towards the bottom. Following the right side of the V from bottom to top, the verification of parts, systems and finally the entire vehicle is carried out.

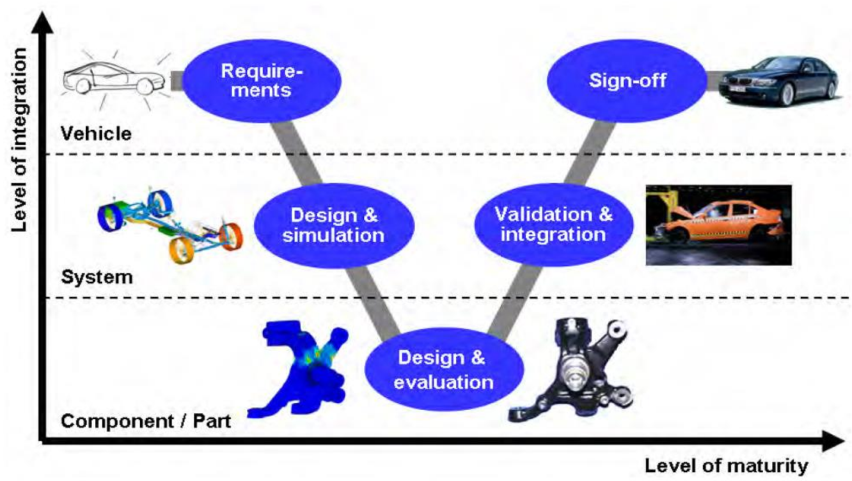

Fig. 1 V-Model of the development process in the automotive industry (Weber 2009)

At the start of the development process, the requirements for the project are set. In a subsequent step, these requirements are translated into functions and technical solutions on a system level. The results from this step are input data for the technical design of individual parts on a component level. Starting with the verification process, these data are also the foundation for the component testing. Once individual parts have sufficient maturity, modules of increasing integration level are tested and released until the entire car is signed off for production.

Looking at the V-Model, it is clear that decisions taken in the very beginning of the project will define the resulting vehicle. Although changes to the original decisions are possible through change-management during the development and testing phase, costs for changes increase dramatically with increasing project maturity (Weber 2009) as shown in Fig. 2. Thus, it is crucial to define valid, reliable project goals, which are in line with customer needs and wants from the very beginning. They define the characteristics of every aspect of the resulting vehicle as well as the premises during the validation process.

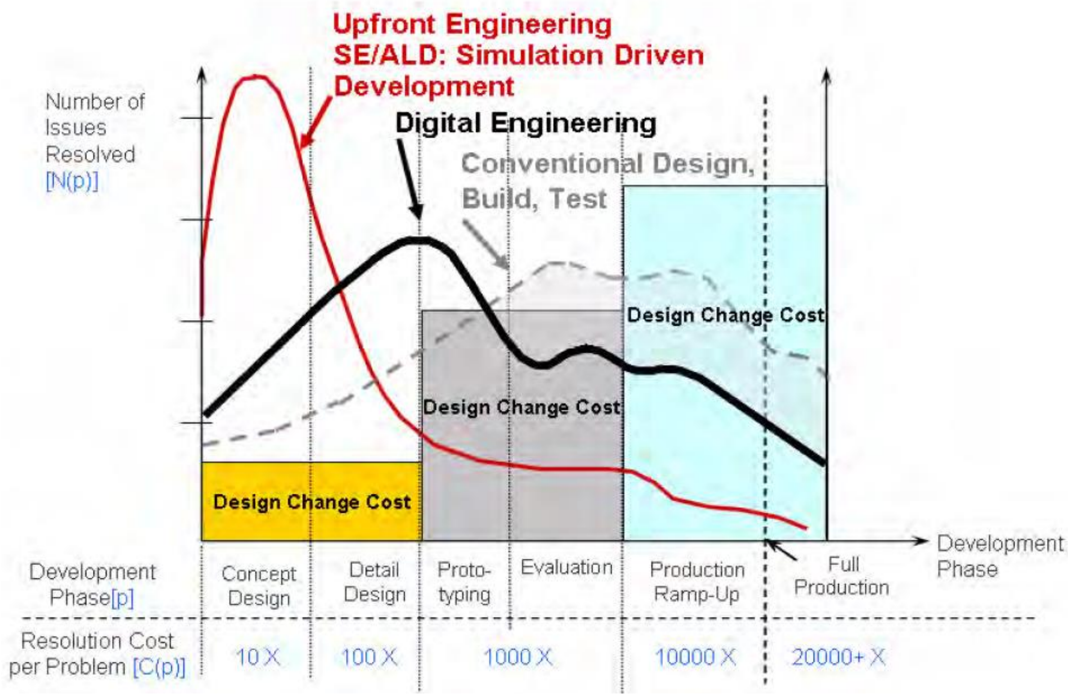

Fig. 2 Development costs and change management costs in automotive development (Lemon 2011)

1.2 Steps of Automotive Development

In the next three paragraphs, the basic steps of vehicle development are summarized. To reduce the complexity and allow for a more applied explanation, each step will be explained along the V-model of automotive development using the development of a vehicle's suspension as an example.

1.2.1 Definition of Market Position and Core Characteristics

The development of a new car typically starts with an executive decision to develop a successor of a current model or a completely new model. In both cases, the management board will, based on data from market research, define the general positioning of the car-to-be. In subsequent steps, R&D will specify the vehicle in more detail by defining targets for characteristics and properties, which describe the car. However, at this point no functions or technical solutions are developed. The vehicle characteristics are quantitative data sets describing a multitude of attributes, which characterize a vehicle. On the one hand, these definitions have to ensure compliance with legal restrictions as well as the roadworthiness of the future car. On the other hand, they define characteristics, which have to meet customer requirements for the targeted vehicle class and customer group. These customer requirements are typically developed from predecessor vehicles (if there is one) and competitor products and are expanded by new technologies and trends to endure competitiveness in the future market when the vehicle is launched. The characteristics are defined on several levels in a top-down manner to evaluate all different customer relevant characteristics ranging from acceleration or suspension firmness to usability of infotainment systems or interior material quality. To quantify these vehicle characteristics, each requirement in the customer domain is evaluated against predecessor vehicles and competitor products either on a normalised scale between 0 and 10 or regarding their differentiation within their segment ("*Best in class*", "*Among top 3*", "*Acceptable standard*") (Weber 2009). In subsequent steps, the vehicle characteristics gain more and more precision until a detailed quantitative definition of the future car is worked out. Since some of these target values might be in conflict to each other (e.g. fuel efficiency vs. acceleration) at this first step of vehicle development, these conflicts between different target values and/or departments have to be solved during the target management process to result with a conflict-free representation of the vehicle to be developed.

Example: Suspension Development (1/4) – Setting Targets for Characteristics

Management has decided to develop a new four door sport coupe in the premium D-segment (according to the European standard car segments (Guzman 2016)). Typical competitors are the BMW 4-series, Audi A5 or Mercedes C-Class Coupe. The vehicle of this example is decided to exhibit a suspension, which is positioned in a firm and sporty segment with still significant ride comfort and low noise level. The positioning in comparison to certain competitor products on the first level of detailing may look like the following diagram:

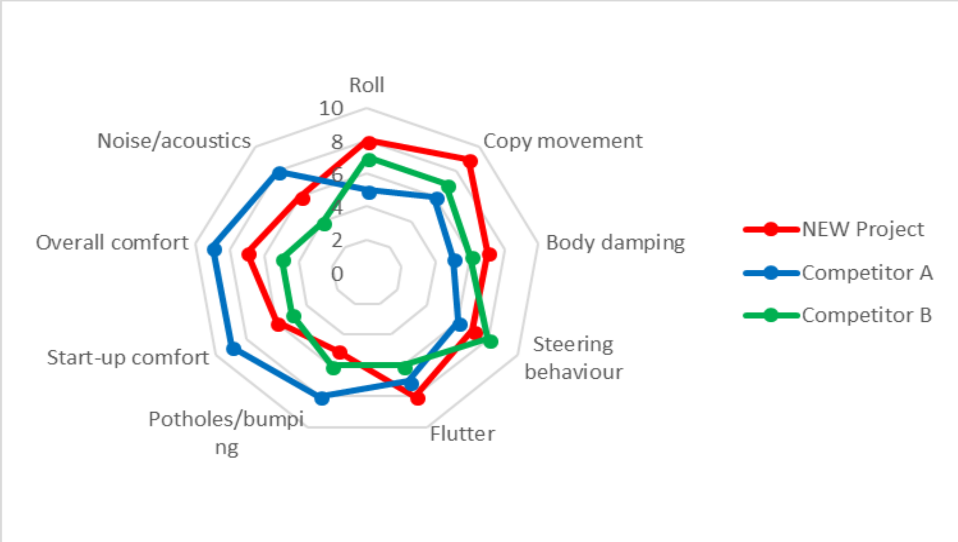

Fig. 3: Example of comparative evaluation of suspension characteristics (Chabot 2013)

1.2.2 Translating Vehicle Requirements into Functions

After the definition of target values for all characteristics describing the new vehicle has been finished, these requirements are translated into functions. Thus, target values are translated from the *customer domain* into a *function domain* (Weber 2009). Functions are only of secondary interest to customers. Developers have to keep in mind that functions and technical solutions don't have an end in themselves but are simply instruments to allow customers to experience the desired vehicle characteristics. Functions are defined on a systems level rather on a vehicle level. They aim at giving technical solutions to individually specified vehicle characteristics.

Example: Suspension Development (2/4) – Defining Functions

In this example, the suspension is positioned in a firm and sporty segment with significant ride comfort and low noise level. To be able to achieve a large spread of spring rate realizing both, a firm and sporty suspension as well as high comfort, it is decided to choose an adaptive multi-chamber air suspension system which allows for changes of the spring rate by switching air-chambers on or off.

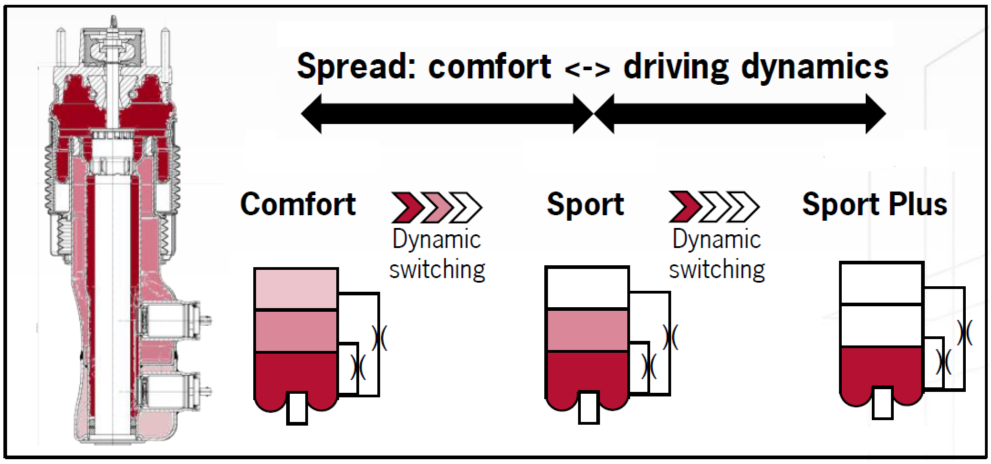

Fig. 4: Example of a switchable multi-chamber air suspension (Porsche AG 2018)

1.2.3 Translating Vehicle Functions into Systems and Components

Once a function that translates customer requirements into technical solutions is specified, a set of physical quantities has to be defined which translates functions into the *physical domain* and fully describes the system and its requirements (Weber 2009). These physical parameters are the foundation of the component development and can contain a variety of quantities. They consist of physical definition of resulting functions, dimensions of the system/component as well as the range of operation conditions, etc. While the physical quantification of functions is determined by the requirements of the *functional domain*, other input variables have different origins. Dimensions are a direct outcome of geometric considerations of the vehicle as well as design space considerations. The range of operation conditions is based on experience from previous developments as well as on assumptions such as customer usage, or climatic, geographic and infrastructural conditions. Furthermore, legal requirements as well as test procedures and technical standards which will apply, need to be specified. All these inputs together result in the specification sheet, which is the basis for component development as well as the benchmark during verification tests. Hidden in these specifications are assumptions regarding customer usage and environmental factors the vehicle is exposed to. Thus, they can be seen as customer related input data of the development process.

Example: Suspension Development (3/4) – Defining Systems and Components

To start the development of the air suspension system, the components have to be fully described by physical quantities. This includes values, which describe the suspension functionality (spring rate, damping, eigenfrequency, noise & vibration, etc.), geometric values (dimensions, weight, suspension travel, interface description to other systems, etc.) as well as values defining the intended use cases (operating loads, failure loads, operating temperatures, corrosion resistance, etc.).

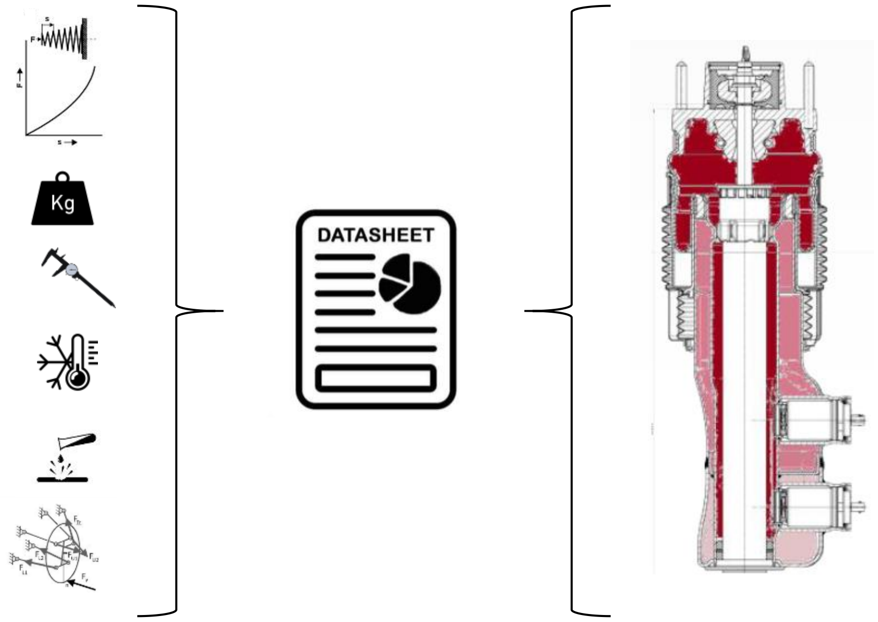

Fig. 5: Technical specification based on functional quantities as well as variables describing design space and operating conditions

1.2.4 Component and Vehicle Testing

Verification and testing of components and systems is done based on the requirements defined in the beginning of the component development and put down into the technical specification document. First verification tests of components are done in an early stage of development with parts from prototype tooling to evaluate the feasibility of the design. These tests consist of individual tests on component level but can also include testing in larger subsystems as well as in entire prototype vehicles. Once it has been shown that the design is capable of fulfilling the set defined requirements, this so-called *design verification phase* is completed with ordering the tooling for series production. The scope of the subsequent *process verification phase* is to show that the series production line is capable of producing parts of sufficient quality. In this phase, again component tests are followed by system and vehicle tests to ensure compatibility of the components in the vehicle system. Changes of the component's design in this later phase are very costly.

Example: Suspension Development (4/4) – Testing and Validation

To complete the design verification and later on the process verification, the air suspension has to pass a number of tests defined in the technical specifications document. The test conditions as well as the evaluation criteria are also predefined in the specifications documents. In this example, the air spring needs to fulfil the following list of tests:

- *Component tests:*
    - *Verification of spring rate and damping*
    - *Individual endurance test under different temperature conditions*
    - *Burst pressure*
- *System and subassembly tests:*
    - *Endurance test of entire axle under corrosion conditions*
    - *Test of time for*
- *Vehicle tests:*
    - *100,000 km endurance test on proving ground*
    - *Misuse test*
    - *Verification of ride and acoustic comfort*

Fig. 6: Design verification and process verification based on tests on component as well as different integration levels

1.2.5 Summary: Customer Oriented Automotive Development

The actual customer requirements are typically unknown to OEMs and their predictions of customer needs are based on customer surveys, sales figures as well as comparisons with competitor vehicles. Based on these sources automakers define a set of variables, which describe the new vehicle in terms of customer requirements.

Using these specifications in the customer domain, the R&D departments develop functions as technical representations and subsequently individual components. When defining each component's technical specifications, again there is an input of data, which is based on certain assumptions of customer behaviour. This second set of customer data might come in disguise of technical standards or test procedures; however, it defines the final product in a very similar manner to the data used during vehicle definition. Thus, when looking at the V-model of vehicle development, there are two instances when customer data is incorporated into the development of a new car as shown in Fig. 7. In a later stage, all these customer-oriented requirements need to be verified before the vehicle fulfils all requirements specified in the beginning and can be released for production.

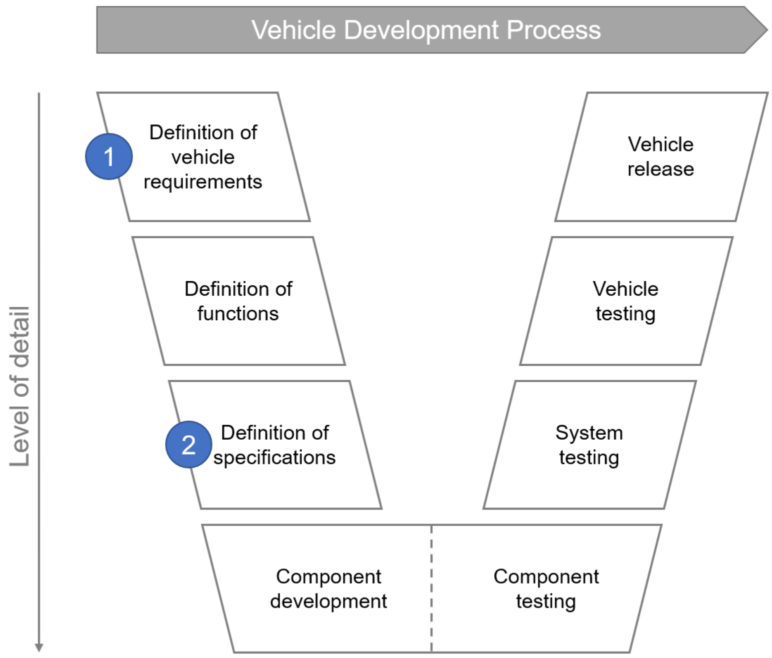

Fig. 7: Vehicle development V-model with customer input during the definition of vehicle requirements ① and during the definition of development specifications ②

Input data representing customer requirements are fed into the development process in ① and in ②. While in ① the known or assumed customer demands are the foundation for the definition of the project on the level of an entire car, in ② another form of customer demands is fed into the development hidden in test specifications etc. Both sets of customer-related input data are relevant to the final product and OEMs should have as clear a picture as possible for both data sets to ensure that the finished vehicle fulfils customer wishes and meets their meet their use-cases in order to guarantee a high level of customer satisfaction.

1.3 Big Data – The Oil of the 21st Century

The widespread introduction of digital functions and software-based value creation has forced industries, such as the automobile industry, whose major income has traditionally been generated by producing and selling physical products, to adapt its business model (Yoo *et al.* 2010). Technological innovations like connected cars or autonomous driving have fundamentally changed the focus of the entire industry and lead to disruptive changes in technology as well as prospective value creation models (Mohr *et al.* 2016, Riasanow *et al.* 2017). The increasing focus on digital technology and the resulting change of business models is likely to attract new competitors. OEMs and automotive suppliers need to be aware of the disruptive nature of the future and will have to adapt their entire strategies to sustain their competitive advantage and keep their new competitors at bay (Riasanow *et al.* 2017).

In many recently published studies, digitalization is seen as one of the megatrends, which will shape the automotive industry in the foreseeable future (Albulescu *et al.* 2015, Bertoncello *et al.* 2016, Kuhnert & Stürmer 2018, Becker 2018). In their annual study concerning the automotive industry's future trends, KPMG ranked digitalization among the two most influential trends in three consecutive years topping widely discussed trends such as autonomous driving or electric cars (Becker 2018).

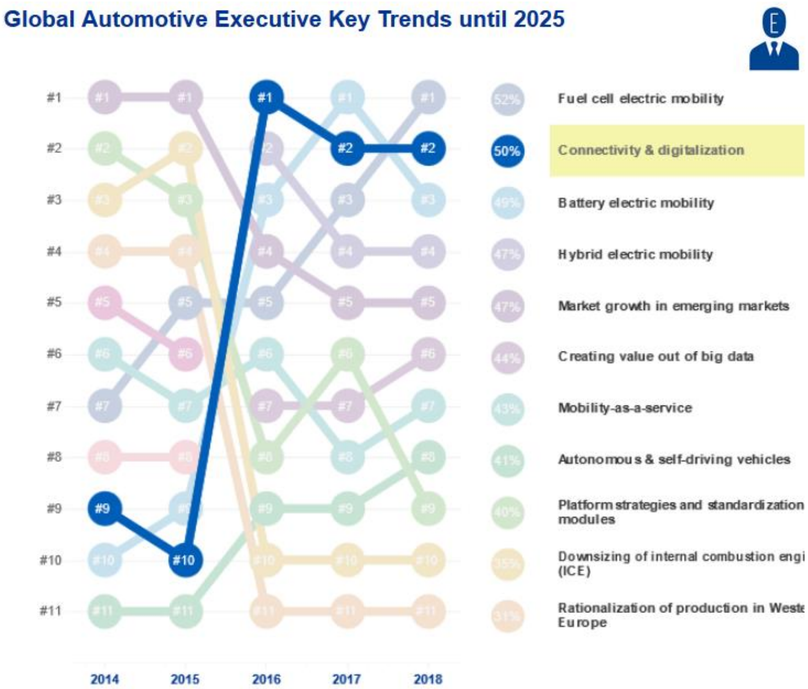

Fig. 8: Automotive megatrends according to KPMG global automotive survey (Becker 2018)

Collecting and analysing data from cars is seen as the main source of revenues in the future of the automotive industry and is expected to exceed revenues made by hardware sales significantly (Wee *et al.* 2015, Mohr *et al.* 2016). A study published by the consulting company McKinsey estimates the expected value of digital revenues in the automotive industry at $450billion to $750 billion until 2030 (Bertoncello *et al.* 2016). Both, KPMG and McKinsey ask which companies will benefit the most from this trend but leave it open whether OEMs, big IT-companies like Google or Apple, or new start-ups will manage to generate the lion share of the estimated profit. However, a study published by PricewaterhouseCoopers (PwC) expects a preliminary decision on who will benefit the most from access to vehicle data within the years 2020 to 2025 and sees OEMs and suppliers as very vulnerable in the battle against falling margins from their traditional business model (Kuhnert & Stürmer 2018).

To be able to exploit the full potential of analysing data from customer vehicles, companies have to develop capabilities to handle large amounts of data efficiently. Considering the number of vehicles, the sum of data control units in each car and the operating hours, it is apparent that the amount and variety of data will increase rapidly. As soon as OEMs start collecting customer data on a broad scale, they will face a pool of data points that satisfy all of the characteristics of the following definition of Big Data according to (Genovese & Prentice 2011): *"… data is available in very high quantities, transmitted at a high rate, and is varied in structure and quality"*. Handling big data is a new field of expertise for most car manufacturer. If they don't want to be left behind, they advised to develop the necessary competences and implement appropriate systems and processes.

2 Thesis Outline

As discussed in the previous paragraphs, the automotive industry is in the middle of a disruptive transformation process triggered by a change from a hardware-governed industry to a provider of connected mobility. At the same time, the automotive development process is still dominated by methods established over decades of hardware-driven development of cars. The introduction of connected cars facilitates an abundance of possibilities for new business models enabling value creation outside the traditional business of selling vehicles and spare parts. Additionally, a better understanding of customer usage can help automakers to improve their products as well as their development processes. This study aims at the question how OEMs can utilize the data generated by a fleet of connected cars to improve their internal processes in order to increase their market share or reduce their costs.

2.1 Research Question

With the widespread introduction of connected cars, OEMs will have the ability to access various vehicle data from customer cars. This study aims at answering the following questions:

- How can data from customer cars help to develop vehicles with more customer relevance?
- What are the potential gains OEMs can obtain from feeding customer data into their R&D centres?
- Which development tasks can be optimized using data from customer vehicles?

2.2 Research Goal

In this study, a qualitative overview of the potential benefits and challenges of implementing a system feeding data from customer cars into the development process of automobile manufacturers will be given. This report aims at giving a comprehensive summary of the most important aspects to consider when implementing a system to feed data from customer cars into an OEM’s development centre. This includes an in-depth understanding of the current situation within the industry, an evaluation of the legal restrictions, and the customer perception of data sharing with OEMs. As a result, possible use-cases in which automotive development will profit from access to data from customer vehicles are acquired and their benefit for OEM and customers are evaluated. For a more detailed discussion of the consequences, necessary technical and organizational implications are showcased using the example of an OEM’s durability department.

2.3 Research Approach

This study aims at a qualitative assessment of the potential of using data from customer cars in the development centre of an OEM. Chapter 3 is intended to highlight the status quo within the industry in regard to collecting and analysing data from customer vehicles. In chapter 4, privacy considerations are discussed from a legal perspective as well the view of customers. These two chapters are based on journal papers, industry reports, and other publicly available sources. The development and evaluation of possible use-cases for customer data usage within automotive development are derived from nine expert interviews conducted for this study. The interviewees are professionals with extensive knowledge of the developing processes inside an OEM’s R&D department. To allow for a bigger picture and to incorporate different development approaches, the interviewees were chosen to work in different fields and different employers. They are working for four different OEMs in the field of passenger cars or commercial vehicles. To evaluate the validity of previously mentioned use-cases, they were put up for discussion in subsequent interviews. This allowed for a sound feed-back of ideas from earlier interviews.

For are more focused discussion of the potential benefits as well as necessary preconditions, chapter 6 discusses the usage of customer data within an OEM’s durability department in form of a case-study. The author has five years of working experience within durability development and the fundamentals presented in this chapter are based on this knowledge as well as some literature sources. Several use-cases brought forward during the expert interviews aimed at development tasks conducted by a durability department. These ideas as well as their technical implementation were carefully evaluated and reviewed with further durability engineers and a big data analyst.

3 Market Analysis

Under the term *digitalization*, in the automotive industry a wide spectrum of different technical aspects and business models can be brought forward. Vehicle data can help creating value by either selling products or services, by reducing costs for the OEMs, suppliers or customers or by increasing the safety of passengers and other road users.

3.1 Monetizing Automotive Data

It is expected that the value of digital revenues in the automotive industry will reach a volume between $450billion and $750 billion until 2030 (DeBord 2015, Bertoncello *et al.* 2016). There are various examples of potential use-cases in regard to connected cars and how to use the data to produce revenues. To allow for a better classification of this multitude of scenarios, possible use-cases can be divided into four groups according to their effect on vehicle manufacturers:

1. **Direct Monetization**

   Most studies published on digital trends in the automotive industry focus on “direct monetization” of vehicle data (Bertoncello *et al.* 2016, Kuhnert & Stürmer 2018, Becker 2018, Mohr *et al.* 2016, Albulescu *et al.* 2015). This form of business model seems the most natural, as it follows ideas similar to already existing business models based on user data from computers or handheld devices. Due to the similarity with already existing business models developed and refined by IT-companies like Google or Apple, the threat for car manufacturers to lose against Silicon Valley based tech companies is substantial (Kuhnert & Stürmer 2018, Becker 2018).

   A typical example of direct monetization models is personalized entertainment offers (movie streaming, karaoke systems, augmented reality games, …) which will gain interest with increasing autonomous driving capabilities of vehicles in the future. In this field OEMs will struggle to keep competition from IT giants at bay. Tech companies will try to gain access to automobile infotainment systems just like *Apple CarPlay* or *Android Auto* today. At the same time, customers will be reluctant to abstain from the entertainment providers they use at home or on their handheld devices and will abstain from using the system offered by an OEM. Thus, it is likely that manufacturers have to design their in-car systems in a way, that 3rd party companies can offer their service embedded into the vehicle's IT-system to meet customer expectations.

A more car-oriented group of direct monetizing business models is looking at the car as one player in a network of interconnected partners. These concepts want to offer drivers car or traffic related services for a premium. Examples are P2P carsharing (Hegemann 2018), parcel deliveries into the trunk (Etherington 2016), or mobile charging services for electric cars (Hebermehl 2017).

Another form of direct monetization is called *function on demand* (FoD). Instead of equipping a car with only the options a customer ordered when buying the car, OEMs equip vehicles with more capable hardware which can be limited to a restricted functionality through software. The car user can then purchase an activation of additional functions for a limited time. Although this business model seem to have the potential to threaten turnover through selling options at the time of vehicle sale, studies suggest that there is a lucrative co-existence for both sources of income (Prieto *et al.* 2017). Tesla's *Autopilot* is an example for existing FoD offers in today's motor industry. All of Tesla's Model S and Model X are equipped with the cameras and sensors necessary for operating the driving assistance system. However, customers have to pay if they want to unlock the system. In contrast to other typical examples of direct monetization models, FoD is directly linked to the vehicle's core functions and thus OEMs won't have to compete with 3rd party companies.

2. Data Bartering

Data Bartering can be seen as closely related to direct monetization approaches. However, due to OEMs' lack of experience with digital value creation, they sell data collected by customers to 3rd party companies which can offer additional services to vehicle users or use them for personalized advertisement. Currently this is the most popular use-case among OEMs because there is no complete understanding of value creating business cases within the companies yet (Singh 2017). While selling data from customer cars might provide OEMs with additional revenues, there are several reservations to be taken into account. Several scandals with companies selling customer data to untrustworthy 3rd party companies, like the one Facebook had with Cambridge Analytica (Riley *et al.* 2018), has made customers more sensitive about data privacy and security. This makes it increasingly harder for automotive companies to convince customers to give away the data produced with their cars. Companies have to give customers a good understanding of the benefits they gain when giving permission to use their data and it has to be very clear on how data is used (Bertoncello *et al.* 2016). Furthermore, with data bartering OEMs lose the control of the data and become a data harvester for the IT industry. With increasing importance of data related business models as source of value creation, losing the control over data streams yields the risk for automotive companies to be left behind and become a sole hardware supplier rather than a producer of mobility solutions and integrated transportation systems.

3. Network Intelligence

Network Intelligence consists of concepts, which are based on the connectivity of future automobiles and focus on data exchange between vehicles and their environment (including other vehicles as well as infrastructure etc.). This concept, also known as *Car-to-X*, is seen as highly beneficial for the customer by most studies discussing potential business cases for connected cars (Bertoncello *et al.* 2016, Becker 2018, Kuhnert & Stürmer 2018). To allow for maximum impact of network intelligence, a common standard for data handling and information sharing has to be established. Without such a standard, customers were isolated in closed systems with only a fraction of potential data sets available.

Typical examples are road condition warnings such as black ice alerts between vehicles on the same road, traffic guiding systems or toll collection and parking space finder (Bertoncello *et al.* 2016, Barnes 2018, Paul *et al.* 2017).

4. Cost Reduction

From an OEM's perspective, cost reductions from digitalization can be achieved in very different fields. One highly discussed use-case for direct monetizing data is function on demand (as described above). Additional to its potential of generating additional income, it can also help reduce costs for the OEM. When differentiation of certain functions is only done through software, all vehicles will be equipped with the same hardware system, which is capable of the low and high functionality. Although the hardware costs might be higher than for a low-range system with only limited capabilities, development costs as well as complexity in production can be reduced.

Another form of cost reduction in automotive development can be achieved through tailored developing of only those systems and functions customers actually use. All variants, which are likely not to give customers additional benefits, can be left out to reduce the complexity and the development effort.

Avoiding over-engineered technical designs through a better understanding of real vehicle usage promises huge cost saving potential. Today's testing specifications OEMs use to verify their products are based on experiences gained over decades of vehicle development and are updated regularly if new problems or shortcomings have been noticed. Although this approach ensures an increasing level of quality it is prone to result in over-engineered developments. With the ability to analyse vehicle utilization of real customers all over the world, OEMs will have the ability to verify their test requirements and might be able to reduce certain standards without the risk of pre-mature failures. Thus, there is a huge potential of cost savings, which could benefit both, vehicle producers as well as customers.

Customers could also benefit directly from predictive maintenance functions which could reduce service and repair costs of vehicles significantly (Jun *et al.* 2006). Furthermore, in a connected traffic infrastructure with existing vehicle-to-infrastructure communication, drivers could benefit from reduced tolls etc., if choosing certain routes with less traffic (Wee *et al.* 2015, Bertoncello *et al.* 2016) .

As discussed in the previous paragraphs, there are numerous potential value creation models for car data usage discussed in various studies. However, most of the discussed propositions are mere theoretical ideas rather than implemented business models. By 2018, only a minority of cars on the road have a network connection. Up-to-date vehicles offer the option of broadband connections. However, this is mostly used for Wi-Fi hotspots, google maps implementation into onboard-navigation systems or comfort and telecommunication systems such as email and music streaming.

3.2 Current Examples of Car Data Usage by OEMs

Modern cars have hundreds of ECUs which process a vast amount of data during operation of the vehicle. Typically, these data are processed in situ in the car and are deleted immediately after use. If problems are detected, event files and error codes from relevant ECUs are written into the vehicle’s onboard diagnosis system (OBD). Typically, defect code memories store data locally and can only be accessed through a hardware connection to the vehicle’s physical IT-interface, for example during maintenance work at a service station (Cleveland 1995). Typically, the data read from defect code memory are only used locally for repair and maintenance and the memory is erased after the service (Dobromirov *et al.* 2017). Thus, gathering and interpretation of defect code data from a large number of vehicles has not been widely done in the past. However, to a certain extent it is possible to use data from defect code memories for a forensic investigation by legal authorities or insurance companies (Dobromirov *et al.* 2017).

With the introduction of fully connected cars, OEMs gain the ability to access defect code memories as well as live-data from various ECUs remotely. Most well-known is Tesla Inc. which is reported to collect large amount of data from more than 50,000 customer cars since Oct 2016 (Muoio 2017a). In addition to collecting numerical data, in May 2017 Tesla started to collect location, image and video data from customer cars. According to a statement of the company, the video clips and snapshots from the vehicle’s external cameras are not connected to the vehicle’s identification number and are used solely to improve the company’s self-driving capability (Lambert 2017). It is reported, that each Tesla vehicle collects and uploads several hundred MB of data every day giving Tesla a huge amount of data to work with (Lambert 2017).

Tesla's customer privacy policy grants the company access to a wide range of customer data. It allows collecting of all data related to accidents or any technical malfunction and can be accessed either in person during maintenance service or remotely via mobile network connection. According to the privacy policy the following data are collected from customer cars by default (Tesla 2017):

- Telematics log data:

  Telematics log data are not anonymised but directly related to the vehicle identification number. They consist of technical data such as speed, mileage, acceleration, battery usage and charging information. Furthermore, so called "safety-related data" consisting of camera images and video clips from accidents are listed in this section.

- Remote analysis data:

  Remote analysis data is used for remote problem solving of a vehicle's malfunction by a service centre. This allows the company to access personal data such as contacts, web-browser and navigation history, personal settings as well as the vehicles current location.

- Other vehicle data:

  Tesla reserves the right to access all data "*about any issue that could materially impair operation of your vehicle*". According to the company's policy this ranges from honk-the-horn and remote lock/unlock commands to air bag deployments.

- Service history

  Tesla has the right to collect and process service related customer data such as name, vehicle registration number, repair history and "*all other information related to its service history*"

- Charging station information

  Data regarding customer usage of charging stations, charging rate, location and charging duration are collected. It is unclear, whether these data are linked to the user or are anonymised.

- Data for advanced features

  Data for advanced features are used to help Tesla improve their products and services. These data are anonymised (data are not linked to the user or the vehicles registration number) and consist of data related to features such as “Autopilot”, real-time traffic information or “Summon” (system for semi-autonomous parking). These data are collected by Tesla, but the privacy policy allows sharing them with business partners. Furthermore, images and video clips from the vehicle’s external cameras are collected and uploaded to Tesla servers.

Data collection for advanced features is the only option which can be disabled by the customer in the vehicle’s user interface. If customers want to opt out from sharing any of the other data sets mentioned above, they need to contact Tesla via a contact form on the company’s website. However, it is stated in the privacy policy, that opting out from data collection will disable mobile applications such as voice commands, access to internet radio as well as internet browsing. According to its privacy policy, Tesla can share all collected vehicle data “*with our service providers and business partners, with other third parties you authorize, with other third parties when required by law, and in other circumstances*” (Tesla 2017).

Tesla might be the most well know OEM already collecting customer data on a big scale and is the only one who asks customers openly for permission to use their cars’ data for development work. However, many car manufacturers collect vehicle data these days and have privacy policies hidden in their sales and purchase agreements granting them the permission to gather various types of data. Honda, General Motors, Ford and Toyota are reported to also collect data from customer vehicles in the USA (Holley 2018). BMW has established a marketplace for vehicle data called *CarData* which collects telemetric data from vehicles and uses them in BMW’s marketplace (Stumpf 2017). According to information provided by BMW, CarData enables collecting vehicle data such as “*condition data, like mileage; usage-based data, such as average fuel consumption; and event data, like an automated service call*” (BMW 2017). Customers can assign which data they want to share with third parties such as insurance companies to profit from discounts (e.g. lower insurance premiums) or special offers (e.g. personalised infotainment) through an online platform. In addition to OEMs, third party companies work in the field of collecting data from customer vehicles. A data brokering marketplace for car data similar to BMW's *CarData* is established by Israeli start-up company Otonomo. Founded in 2015, it is reported to have attracted $45 million of investment for their business model of offering data cloud solutions and big data capabilities designed to offer "cleaned-up" vehicle data to third party companies via a marketplace (Holley 2018, Singh 2017). Otonomo helps OEMs to fulfil the different legal requirements in various countries (Quain 2017) and is said to collaborate with nine major automakers, Daimler being the only OEM whose name has been publicly announced (Muoio 2017b).

3.3 Summary: Use of Data from Customer Vehicles

It is expected that business with vehicle data will be a multi-billion-dollar business within the next decade (Bertoncello *et al.* 2016). There is wide variety of possible use-cases published and a multitude of different companies are positioning themselves to earn their share of this new business field. So far it is still unclear who will lead the race for profit from vehicle data and a fierce competition between traditional automotive companies and IT-giants can be expected. Furthermore, there are several start-ups, who will try to find their niche in this new field of business. Most new business ideas mainly focus on direct monetization models offering customers additional services in the mobility sector. With only limited experience of making money from digital services, with data bartering automakers have found a way to create additional revenues from vehicle data by teaming up with other companies who have more experience in digital business sectors. For example, the Israeli start-up company Otonomo is reported to provide data analytics services for several OEMs.

Many automotive companies already collect data from customer cars in one way or the other. However, many of them seem to be coy about the extent and usage of data collection and details can only be found in the small print of purchase agreements or in lengthy terms and conditions of certain features. Today, Tesla is the only OEM who has acknowledged to use data from customer vehicles for improving their products by feeding them into their development centre. Customers are offered an easy system to opt-out of sharing their data with R&D at any time.

4 Privacy Considerations

Privacy considerations are a very sensitive and hence a very important aspect when it comes to using data collected from customer cars. For an internationally operating OEM there are various different legal frameworks in different markets and regions which have to be followed. These legal requirements are setting the minimum level of data privacy automakers will have to establish. Furthermore, customers' need for privacy and their concerns regarding data security have to be taken seriously by OEMs and have to play a major role when implementing such a system.

Modern cars have a vast number of sensors, cameras and other hard- and software devices, which constantly produce and record data. Soon, a significant amount of these data can be transferred from the vehicle to OEM servers. There are various designated use-cases for OEMs to collect these data (as discussed in chapter 3) varying from offering additional customized services, to improving their products and services, to selling data to third party companies for cash. However, some of the transferred data sets could be considered private. An obvious gateway into customers' personal lives are the GPS location data which, connected with a time stamp, can tell anyone with access to it a lot about the driver's habits and routines. GPS location data, acceleration, braking or speed information could be useful for businesses to offer tailor-made service packages to the vehicle owner (for example used-based insurance), but it could also be used against the driver's will, for example by governments to track their citizens' following of speed limits etc. (Kohler & Colbert-Taylor 2014, Quain 2017). Apart from such obvious car data sets, vehicles are reported to track and transfer even more personal data. In 2015 the General German Automobile Club (ADAC) found out, that BMW transferred details of phone calls, the contact lists of connected mobile phones as well as text messages and browser history to BMW-owned servers (Roe *et al.* 2017). According to Tesla's privacy terms, the company is entitled to access video and audio files from within the car as well as from the vehicle's surrounding (Tesla 2017). Furthermore, modern cars can tell individual driver's characteristic such as height, gender or personal health status (Barnes 2018).

With *Goggle StreetView* the first controversy with high media attention in the borderland between automotive and IT industry was widely discussed in the late 2000s and early 2010s (Bloom *et al.* 2017). To offer consumers a photographic image of all streets in their widely used Map application, in 2007 Google started to equip cars with 360-degree cameras taking pictures of all cartographed roads in the USA and published the images embedded in their publicly available *Google Maps* application. In subsequent years, the company deployed this service in various countries all over the world. Especially in European countries, there was a fierce debate regarding the implication on privacy of road users as well as properties whose image had been taken and published. Eventually, Google had to improve the anonymization of road users (faces, number plates, etc.) and home owners in certain countries could legally enforce the pictures of their homes to be blurred out on request (Richard 2010). This example shows that there is a need for privacy not only for users of connected cars themselves but also for people sharing the same habitat. OEMs and other companies will have to persuade users of connected cars for consent to access their private data. However, with outside-facing cameras etc. other road user's privacy might also be infringed and it is still unclear how this issue can be solved adequately (Bloom *et al.* 2017). Furthermore, there were several cases that Tesla published detailed data from customer vehicles involved in serious accidents without asking the vehicle owner or their surviving dependant for permission (Pentland 2018, Plungis 2018). Thus, it seems inevitable that privacy regulations regarding personal data from connected cars need to be introduced, at least to some extent, on a legal basis; a self-regulation seems not sufficient and might result in an imbalance between consumers and industry or monopolies similar to those seen in online marketing (Pentland 2018).

On a technical level, data privacy can be implemented into vehicles in different ways. Two widely discussed concepts are *privacy by default* and *privacy by design* (Weinberg *et al.* 2015, v. Schönfeld 2018, Pentland 2018, Roe *et al.* 2017, Duri *et al.* 2002, Cavoukian 2011). The concept of *privacy by default* means that the default privacy settings of a system are set to the highest data protection level. Users have to actively change the privacy settings if they wish to share more information (v. Schönfeld 2018, Cavoukian 2011). When considering discussions regarding data collection of large IT companies such as Google, Facebook or Microsoft, it is apparent that these companies do not comply with this principle and seem to follow the opposite principle of transparency by default (Foxx 2018a, Foxx 2018b). *Privacy by design* is defined by the implementation of privacy consideration throughout the entire developing process from project start until final release (Weinberg *et al.* 2015). This necessitates the collaboration of development teams with legal advisers throughout the development with an holistic privacy approach in mind (Roe *et al.* 2017). According to Cavoukian (Cavoukian 2011) privacy by design is based on seven principles:

- Proactive rather than reactive privacy action
- Highest privacy settings by default ("privacy by default")
- Privacy as an embedded core element of a system rather than an add-on
- No loss of functionality due to privacy settings
- Data security over the entire data collection and processing lifecycle
- Transparency of data collection, usage and transfer
- Privacy interests of individuals has highest priority

4.1 Legal Requirements

The legal framework regarding privacy regulation for connected cars vary significantly between different countries. Similar to the existing regulations regarding web-based services, policies in the USA are rather business friendly, while European legislation has a focus on data protection and privacy needs of the general public. In regard to the legal framework of data protection, the US policy differentiates clearly between commercial use of data and data access by authorities. While in the USA there are legal restrictions for data use by law enforcement agencies and other authorities, almost no regulation regarding the commercial use and transfer of private data for business purposes exists (with the exception of medical information) (Kohler & Colbert-Taylor 2014, Quain 2017). The federal Driver's Privacy Protection Act (DPPA), which became effective in the U.S. in 1994, protects all individual data held by state motor vehicle departments and allows data transfers only in clearly defined exceptions (Glancy 2015). Furthermore, there are laws governing the use of data stored in "black-boxes" installed in cars which store data just before and after a crash (Quain 2017). When granting authorities access to personal vehicle data, the main legal question in the USA is, whether the user can have a "reasonable expectation of privacy" in his doings. If this is the case, governmental access to such data is, according to the Fourth Amendment's privacy guarantee, illegal (Kohler & Colbert-Taylor 2014). However, this limits only direct access from authorities. If users gave businesses access to these data voluntarily, law enforcement agencies can obtain these “business records” without a per-se violation of the Fourth Amendment (similar to mobile phone data obtained from network providers) (Kohler & Colbert-Taylor 2014). In contrast to the restrictions of data usage by authorities, in the U.S. there are no federal laws which regulate the commercial use and transfer of data generated in a vehicle. Until today, there are only self-regulatory guidelines. The main self-regulatory framework has been developed by the Alliance of Automobile Manufacturers representing 20 automakers selling cars in the USA which consists of seven voluntary “Privacy Principles” (Barnes 2018, Plungis 2018). It is the dominant outline regulating the use of vehicle data and related privacy issues in the United States (Barnes 2018). However, the guidelines are formulated vaguely and give lots of room for interpretation by the OEMs. In detail they consist of the following rules (ALLIANCE OF AUTOMOBILE MANUFACTURERS 2014):

- **Transparency:**

  Participating Members commit to providing Owners and Registered Users with ready access to clear, meaningful notices about the Participating Member’s collection, use, and sharing of Covered Information.

- **Choice:**

  Participating Members commit to offering Owners and Registered Users with certain choices regarding the collection, use, and sharing of Covered Information.

- **Respect for Context:**

  Participating Members commit to using and sharing Covered Information in ways that are consistent with the context in which the Covered Information was collected, taking account of the likely impact on Owners and Registered Users.

- **Data Minimization, De-Identification & Retention:**

  Participating Members commit to collecting Covered Information only as needed for legitimate business purposes. Participating Members commit to retaining Covered Information no longer than they determine necessary for legitimate business purposes.

- **Data Security:**

  Participating Members commit to implementing reasonable measures to protect Covered Information against loss and unauthorized access or use.

- **Integrity & Access:**

  Participating Members commit to implementing reasonable measures to maintain the accuracy of Covered Information and commit to giving Owners and Registered Users reasonable means to review and correct Personal Subscription Information.

- **Accountability:**

  Participating Members commit to taking reasonable steps to ensure that they and other entities that receive Covered Information adhere to the Principles.

These principles are defined as general agreements only and automakers are free to incorporate them in different ways into their individual privacy regulations. Despite these self-imposed regulations, the national Government Accountability Office (GAO) found existing privacy terms published by automakers in the United States lacking plain language and clear information regarding data sharing with third parties. Furthermore, it was criticised by the GAO, that although all OEMs ask for user consent before data is collected, opting-out typically means stopping all connected vehicle services (Office 2017). The consent for data collection is mostly given through certain sections in the vehicle's purchasing contract or through a click within an in-car app accepting the terms and conditions (Barnes 2018, Quain 2017). Since there is no legal framework for data collection by businesses in the USA, changes to the terms and conditions can alter the extent of data collection and data exchange with third parties significantly. For example, in 2017 General Motors changed the policy for their OnStar® communication system allowing data transfer to third party businesses without asking customers for explicit consent by just altering the terms and conditions (Quain 2017).

In Europe regulations regarding privacy of private data is regulated much more closely than in the US. The European Union recently introduced a strict set of data protection rules in form of the General Data Protection Regulation (GDPR), which gives customers an increased sovereignty over their data stored by various businesses. This new set of rules allows to punish non-compliant businesses with penalties up to 4% of their global turnover (Roe *et al.* 2017). Thus, for a company like Volkswagen with revenues of several hundred billion Euros, penalties of a few billion Euros are at stake.

According to GDPR customers have…

- ... to actively opt-in to allow businesses to collect data

- … the right to know which data of them is collected and stored
- … the right to correct the stored data
- … the right to have their data completely deleted from a company's servers

Especially the last point will be difficult to establish for companies, as they have to make sure that all data on all different platforms are fully deleted (Roe *et al.* 2017). However, despite this strict legal framework, the question of who owns the data collected from customer cars is still not entirely answered yet. National legislation, for example the German Civil Code (BGB), is written for the exchange of goods and services and data is not considered as an object of legal protection (v. Schönfeld 2018).

4.2 Customers' Privacy Needs

In addition to the legal restrictions of customer data usage, OEMs also have to abide by customers' personal need for privacy and data security. This factor is probably the most crucial point for companies, as without consent of their customers they will not be able to collect and analyse customer data. However, the question is how sensitive consumers are regarding sharing data, even personal data, which can enable third parties to obtain very detailed information of a person's daily life. Many internet-based service providers already collect and analyse personal data of their customers and sell them to 3rd parties. Despite these privacy issues a majority of people use such services and don't bother to increase privacy settings where possible (Protalinski 2012). This leads to the assumption, that users of connected cars might already be used to sharing personal data with companies and might not see a big change when sharing data from their cars in addition to the data from other sources such as mobile phones or personal computers (Bloom *et al.* 2017). The assumption that data privacy is no major road block on the way to connected cars is backed up by studies concluding that up to three quarters of potential users, accustomed to data sharing through mobile devices, are willing to give companies access to their car data (Bertoncello *et al.* 2016, DeBord 2015, Wee *et al.* 2015). Cyber security is reported to be of higher concern to customers than privacy concerns regarding the type and nature of data transmitted OEMs and other companies seen as trustworthy (Wee *et al.* 2015). Studies show that customers are apt to share personal data if they obtain a personal benefit or understand the resulting gain for the general public (Bertoncello *et al.* 2016, Barnes 2018). A Survey conducted for

(Bertoncello *et al.* 2016) revealed that the vast majority of customers in China, USA and Germany alike are happy to share data when benefitting in terms of safety, cost, convenience and time. The detailed level of acceptance, however, varies considerably between regions, age groups, as well as usage behaviour and is dependent on the particular reason for data collection. Young drivers as well as drivers who spend more time in a car rate the potential benefits of data sharing higher than the involved risks. While 90% of Chinese motorists would be willing to share vehicle data for predictive maintenance reasons, the general acceptance level in Germany and the USA are considerably lower and have a different scope (see Fig. 9). With an acceptance level of 70% for connected navigation, U.S. customers are significantly more willing to share their data than German customers whose use-case with the highest acceptance level is supported by only 60% of drivers (Bertoncello *et al.* 2016).

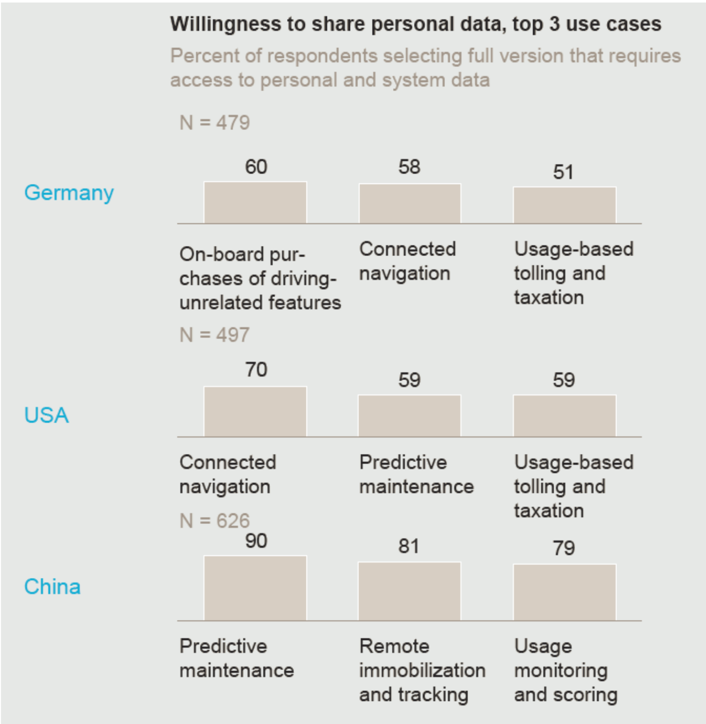

Fig. 9: Willingness to share data depending on region and use-case (Bertoncello *et al.* 2016)

When it comes to data collection for R&D purposes, only 24% of potential customers are reported to refrain from sharing vehicle data with the OEM. More than 50% would share their data with OEMs straight away while another 21% would do so under the condition that the collected data were not sold to 3rd parties (Bertoncello *et al.* 2016).

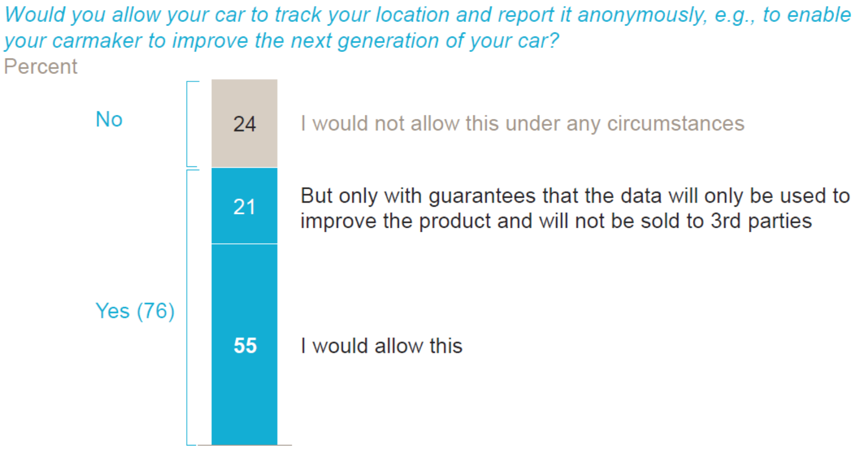

Fig. 10: Willingness of customers to share data to help OEMs improve the next generation of cars (Bertoncello *et al.* 2016)

This finding represents a strong bond between customers and OEMs and implies that carmakers are considered as reliable and trustworthy companies. However, the study also shows, that customers are more willing to share personal data with providers of applications and operating systems for smartphone than with automotive companies (Bertoncello *et al.* 2016)..

Already, vehicles can capture videos from their surrounding and transfer them to data analysts. In addition to OEMs who might use such data for improving their driver assistance systems, there might be other parties interested in this kind of information. Information of vehicle identification of other road users could be of interest for insurance companies as a source of information about the driving behaviour of their customers lading to an individual risk assessment against the customer's will (Pentland 2018). Other companies such as Facebook or Google whose business model is based on selling personal data for commercial use might also be interested in adding data of road users to their existing data pool. The knowledge of a person's driving behaviour and typical destinations in combination with this individual's personal data from other sources is seen as a potential gold mine for businesses (Pentland 2018). In addition to their own customers, OEM will have to convince the general public that the existence of connected cars will not impose a threat to the privacy needs of other road users.

4.3 Summary: Privacy Regulations and Consumer Privacy Needs

In summary, the question who owns personal data produced by connected cars, is still not answered adequately (v. Schönfeld 2018) and both, industry and legislative authorities, need to address this subject with users' right for privacy and data security as top priority. OEMs have to take privacy consideration in terms of legal restrictions as well as customer needs and feelings into account when developing connected cars. While the legal framework for data collection is rather faint in the U.S., the latest European laws on data protection and privacy impose strict limitation on how businesses are allowed to collect and store personal data. The new GDPR-legislation oblige companies to implement privacy-by-default mechanisms into their system, which necessitates users to actively opt-in to data collection by companies. In regard to connected cars OEM have to actively convince customers to give access to data produced with their cars. However, surveys showed, that customers are already used to give companies access to their data and a majority is open to sharing their data with automobile manufacturers (Bertoncello *et al.* 2016). Many customers realize the value of data and hence they expect a considerable benefit for giving companies access to their personal data. Furthermore, many customers are sensitive when it comes to personal data being transferred from the data collector to third party companies. OEMs should take that in mind and assure customers that their data will not be used for any other purpose than the one agreed to. The case is getting more difficult if data of people other than the vehicle user is collected and analysed. OEMs are well advised to be transparent about their data collection in terms of quantity, quality as well as the intended purpose. It seems advisable to invest in cyber security as well as in communication measures to inform customers as well as the general public in good time about the planned data collection programs. To account for the concerns of customers, they should be asked before gathering personal information such as geolocation or videos and should have the ability to turn data collection off anytime. OEMs have to be aware, that a single example of data mismanagements could lead to a significant damage of reputation. OEMs need to evaluate carefully, whether the potential benefit of selling data to third parties will exceed the risks involved with losing control of data produced with their cars and the potential damage to their brand image.

5 Internal Stakeholder Analysis

It is assumed, that there are various applications for the use of data from customer vehicles in an OEM's development department. To establish a better understanding of the different development tasks and to gain an overview of possible use-cases, nine expert interviews with professionals form the automotive industry were carried out for this study. These experts were working for four different OEMs in the field of passenger cars or commercial vehicles and had an in-depth knowledge of the developing processes inside the R&D department of large automotive companies.

5.1 Expert Interview Outline

Prior to the interview, a short summary of the subject of this study was sent to each participant as a means of preparation. This summary was accompanied by a set of introductory questions (see Appendix A.1). Depending on the availability, the interviews were conducted in person or via telephone. Strict confidentiality was assured to encourage participants to speak openly. Thus, names of participants and companies are not published. Each interviewee received the interview summary to be able to delete statements not meant for publication. The interviews lasted between 25 and 70 minutes.

Firstly, the aim of this study was presented and a general explanation of the technical possibility of transferring data from customer cars to OEM servers was given. In the next phase of the interviews, those interviewees who work in development were asked about their field of work and where the information they need is derived from. The aim in this part of the interview was to establish together with the interviewee, whether in the particular field of work input variables are used that are based on customer requirements and/or assumptions regarding the typical use of customers. In some cases, there were direct links to customer requirements while in other cases customer input was hidden within development standards or test specifications. In a next step, the experts were asked for their opinion on the use of customer data in their field of work and whether they could think of situations in their daily work where a better knowledge of customer behaviour would help to improve the development. Finally, all participants were asked in which other fields of vehicle development they would see potential of using real customer data as an input and which advantages could be gained by doing so.

A summary with the most important findings of each interview is presented in the appendix section A.2.

5.2 Economic Potential of Feeding Customer Data into R&D

During the interviews carried out for this study, various possible applications for using data from customer vehicles in automotive development were discussed with the interviewees. In addition to discussing the technical problems which could be solved using customer data, the potential benefit of each idea was reviewed. All use-cases brought forward during the interviews facilitate at least one cost saving or profit increasing aspect to the OEM. Some of the ideas have the potential to have a positive impact on several aspects of cost structure and generation of revenues. The following five groups of possible economic benefits were derived from the use-cases and their respective benefits brought up during the interviews. They represent a qualitative representation of possible benefits and were named several times during the interviews (see appendix section A.2). A quantitative evaluation of the profitability of a valid use-case will depend on individual factors of the respective project and can’t be answered in general.

5.2.1 Higher Revenues

Using customer data for automotive development can increase revenues in different ways. On the one hand, access to customer data can help OEMs to develop products, which offer more relevance and higher additional value to customers. On the other hand, OEMs will get a better understanding of the differences between different markets as well as implications to their business models.

Increased Market Share

With access to customer data, OEMs will be able to understand the needs and wishes of customers rather than making assumptions regarding customer wants. Future products will be tailored to give customers additional value resulting in higher customer acceptance. Ultimately, this will help OEMs to increase their market share and thus their revenues.

More Accurate Definition of Market Restrictions

Customer data will not only give insight into customer behaviour but will also tell OEMs about external factors prevalent in specific regions. With access to this information, automakers will have a more precise understanding of country-specific conditions than they have at the moment. Regional restrictions, which are in place for certain vehicles or profitable options (e.g. large wheels), could be reviewed and possibly lifted if feasible.

Better Organization of Business Models

With a better understanding of customer usage, pricing of options can be done more strategically in a way that, for example, options with more relevance to customers are priced with higher margins than those hardly ever used. Furthermore, with the introduction of function on demand (FoD) business models, customer data can help OEMs to decide which kind of sales option (traditional sale of option at vehicle purchase or FoD purchase) is more profitable.

5.2.2 Reduced R&D Costs

With the ability to access customer data, OEMs could possibly reduce costs within their R&D departments by reducing the effort in fields not seen significant to customers. Furthermore, access to customer data will give OEMs data for free, which otherwise they had to produce themselves using a fleet of test vehicles.

Focus on Functions with Real Customer Benefit

Functions that are not regularly used by real customers can be evaluated as superfluous in regard to their customer benefit. It can be assumed that customers will not order the same feature in their next car again if they hardly use it. Thus, these functions can be omitted in future developments without compromising customer experience or jeopardize revenues. Thus, the development effort and consequently the costs involved with developing these features can be saved.

Using Customer Data in addition to Data Produced with Own Test Vehicles

OEMs operate big fleets of test vehicles to produce input data for the development (e.g. load data, temperature data, etc.). This work is very costly since a lot of capital is tied-up in the large number of vehicles and highly paid employees are necessary to produce the data. With access to customer data, automakers will get larger samples of these data for free. This will not make test vehicles for data acquisition obsolete, but it can help to reduce the number of vehicles necessary and thus reduce the costs for data acquisition.

5.2.3 Reduced Unit Costs

The automotive industry is very cost sensitive, especially when it comes to unit costs. With millions of cars sold every year, savings of a few cent can already have a huge cost saving potential for the company. Thus, being able to reduce the unit price of certain parts or even dispose of some parts altogether could mean a huge cost saving potential.

Omitting Parts or Functions without Customer Benefit

If data from customer vehicles show that certain functions are hardly ever used by customers, these functions can be left out in future developments. Thus, if these parts are not priced as options but are part of the base model, the entire unit costs for these parts can be saved without compromising the user experience.

More Accurate Test Requirements

With a better knowledge of customer behaviour, assumptions regarding vehicle usage, which is incorporated into many test specifications, can be updated to represent more realistic assumptions of customer usage. Many interviewees expected a reduction of certain requirements based on the analysis of customer data resulting in less conservative test specifications. Thus, weight and costs of relevant components can be reduced without risking premature defects.

5.2.4 Reduced Warranty Costs

Based on data from real customer cars, more realistic assumptions regarding the typical use of vehicles in different sales regions can be obtained. Based on these insights, more realistic designs can be developed. This can result in a reduction of certain requirements leading to lower unit costs. However, the analysis of data from customer vehicles can also lead to the development of higher or new test standards to account for vehicle usage not yet accounted for. Thus, costs for potential warranty claims and customer dissatisfaction due to premature failure can be avoided.

5.2.5 Reduced Logistics Costs

If customer data shows that certain parts are not needed in the future anymore, this will not only result in savings in terms of unit price but also in a reduction of complexity. Thus, savings within the assembly process as well as the logistics department can be expected.

5.3 Possible Use-Cases for Customer Data Utilization

When discussing the different sources of information used in vehicle development, all experts working in development agreed that there are two major flows on information regarding customer input:

1. Direct customer requests defined in the definition phase of the vehicle
2. Indirect assumption of customer usage through developing standards

Interestingly, the second way of indirect input was named as more important for their own work by most of the R&D experts and the accuracy of the underlying assumptions regarding typical customer usage were widely questioned. Many interviewees saw a potential risk of developing over-engineered solutions due to continuing increase of requirements over the years. Access to real customer data is seen as a potential corrective with the potential of significant cost reduction through singular adjustments of certain requirements or test specifications.

Furthermore, the accuracy of forecasts published by the sales department regarding customer wishes was questioned. It was mentioned that many options are developed which later are hardly ever sold to customers. A better knowledge of customer usage of functions, it was said, would help development departments to focus on relevant functions and save the resources of functions hardly used. This could reduce the costs occurring in R&D as well as unit price and logistic costs.

The development of new technologies in which currently OEMs have little experience was named as another field of possible application of data from customer cars. Using customer data in addition to data from vehicle fleets operated by the OEM, a bigger data base could be established in short time giving developers a better foundation for a *right-first-time* development.

Due to the differing professional backgrounds of the experts interviewed for this study, a wide variety of applications for using customer data in vehicle development was brought forward. The most prominent examples will be discussed in the following paragraphs. To give a more structured overview of the possible use-cases, the ideas have been structured according to their fundamental aim.

5.3.1 Tailored Development according to Customer Wishes and Usage

Four interviewees mentioned the lack of actual knowledge about customers' wishes. They do not trust the customer requirements formulated by the sales department and doubt the reliability of these forecasts. Two of them mentioned different cases in which actual sales figures of certain options were completely different from predictions. A quantification of actual customer usage is seen by all interviewees as a reliable indicator for customer wants and needs. They acknowledged that this is a past-oriented approach as only data of functions already available to customers can be analysed. However, when looking at preferred settings and adjustments of certain functions, customer wants as well as problems or annoyance could be extrapolated. This knowledge could then be used for future developments.

Counter of Function Utilizations

With access to data from customer cars, a counter of function usage could be implemented to track the utilizations of certain functions. Analysis of customer data could tell which functions are actually used and which are obsolete. If OEMs found out that some of functions are hardly ever used, effort and costs for the development could be saved without compromising the user experience for customers. Consequently, components could be omitted resulting in lower unit prices and reduced logistic costs.

Examples:
- How often is a button pressed?
- Do customers ever manually switch headlights on and off?

Benefit:
- Lower R&D costs
- Lower unit costs
- Lower logistics costs

Prediction of Wants from Preferred Settings and Driving Behaviour

In addition to simple counting of utilizations, the behaviour of customers could, if properly analysed, give OEMs clear indications regarding customer wishes. Especially an analysis of the settings most customers use for certain systems would tell OEMs the preferred adjustment. Based on this knowledge OEMs can set the values of the default settings in future cars according to customers' typical settings. Furthermore, if there are significant region-specific differences, market-specific settings can be implemented. Furthermore, evaluation of general driving style can give

OEMs the ability to assess whether features which increase driving dynamics but costly in terms of CO_2 emissions are useful for a typical customer.

Examples:

- If customers with adjustable suspension use comfort mode most of the time, there is need for a more comfortable base setting
- If a large percentage of customers use the air conditioning or the heated seats on full power, it is likely that they would use an even higher setting if available
- If acceleration data show that most customers are driving carefully rather than sporty, tyres with low rolling friction might be ok for most customers

Benefit:

- Higher revenues through higher market share
- Lower unit costs through reduced CO_2 emissions (penalties)

Usability of Infotainment:

Today, the usability of digital user interface and infotainment systems is a very significant factor for customers' purchasing decisions. Thus, OEMs should carefully assess how customers experience the usability of these systems. Vehicle data can help OEMs understand how customers use the systems, what they look for and how much they are distracted when using them (especially with more and more touchscreens replacing physical buttons). Data analysis can help OEMs to change their systems to offer better ergonomics. Adaptations which enhance the user experience and safety can be introduced in future generations of cars or through system updates to.

Examples:

- Assessment of operating errors (off target touch) in order to develop better ergonomics (e.g. change size and positioning of touchscreen buttons depending on driving situation)
- Assessment of level of distraction (e.g. steering behaviour, lane assist) for different functions. If level of distraction is too high these functions should be blocked during driving
- Functions which are used frequently should be accessible on home screen while other functions could be placed in sub-menus

Benefit:

- Higher revenues through higher market share

Trend Scouting

In addition to evaluating the behaviour of customers to predict how they want existing functions to work, analysing customer data could also help to detect future trends. An early knowledge of future customer wishes will help OEMs to develop vehicles according to the latest customer requirements.

Examples:
- What do users search for when using the internet connection of the vehicle?
- Which apps are used on mobile phones connected to the car?

Benefit:
- Higher revenues through higher market share

5.3.2 Improved Accuracy of Internal Test Standards

In many aspects of automotive development, internal or industry-specific standards are the foundation of component and system design. These standards have developed over several decades of vehicle development and account for various problems experienced during these developments. They come in different forms and can influence development in many ways. In early phases of development, they shape the outcome by assumptions of typical use while in later stages they are the backbone of many test scenarios used to verify components and vehicles. Among the interviewees working in R&D there were serious concerns that these standards tend to lead to over-engineered solutions as they incorporate all problems of past developments without having a corrective to reduce specific requirements again. Being able to adjust testing standards to real customer behaviour was seen as the most important use-case for using customer data. Furthermore, using customer data to correct internal standards was regarded as the most influential use-case to reduce costs.

Usage Counter / Timer

For the design of each component of a vehicle, certain assumptions regarding their usage over the lifetime of the vehicle have to be made. These assumptions are one important input parameter of the technical design of each component. With more accurate data regarding how often a certain component or function is used, a more realistic design can be accomplished. Thus, premature failure as well as costly and heavy over-engineered solutions can be avoided.

Examples:
- How often is the alternator in a hybrid car used?
- How many hours is the engine fan running?
- How often is the seat adjusted?

Benefit:
- Lower unit costs
- Lower warranty costs

Usage Patterns

The development of some vehicle systems requires, in addition to scalar quantities such as number of utilizations or hours of usage, more complex assumptions regarding a typical usage. In some situations, these assumptions define the most critical load case and can govern the design of relevant components. Thus, a realistic assumption is crucial to prevent premature failure or overengineered designs.

Examples:
- How high is the percentage of use on motorways, country roads and city roads?
- What is the typical loading situation? How often is a vehicle used fully loaded, with only one passenger, etc?
- How often is full power of engine used?
- How often is full steering angle used?
- How much is a sportscar used on a race track?

Benefit:
- Lower unit costs
- Lower warranty costs

Verification of Extreme Situations

The development of some components is governed by load cases representing extreme scenarios. For safety relevant parts of the vehicle's safety cell that could be a crash test. For other parts these could be a scenario of a fully loaded car with a trailer going down a mountain road etc. While it is important that OEMs ensure the safety of their vehicles even in extreme situations, which are considered to be outside the typical use, some of these test scenarios are the governing factor for design and cost of some components. Thus, a sound analysis of the likelihood of such situations can help OEMs to evaluate whether their current set of extreme tests is sufficient, insufficient or excessive. Even a small reduction of some test conditions could reduce weight and costs significantly.

Examples:
- Do customers with heavy trailers drive mountain roads?
- How often do misuse conditions (e.g. pothole impact at high speeds) occur?
- How often do customers slip off the clutch?

Benefit:
- Lower unit costs
- Lower warranty costs

Re-Design of Development Models

In vehicle development various models of approximation and verification are used which have been developed over the years. However, due to changes in technology, these models might not be valid anymore. Customer data can help to verify existing models and allow the implementation of adjustments if necessary.

Examples:
- Customer data can be used to verify a model to approximate the torques acting on drive shafts (due to large number of combinations of engines and gearboxes, the torques acting on the drive shafts are approximated rather than measured)
- Re-design of test tracks to account for SUV-specific loading (current test tracks have been designed for passenger cars, which exhibit different kind of loading than SUVs with their larger suspension travel etc.)

Benefit:
- Lower development costs

Customer Test Fleet Model with Added Sensors

In addition to evaluating customer behaviour based on sensors already implemented in each vehicle, the accuracy of existing data could be improved by additional sensors implemented in only a certain number of customer vehicles. Although this would increase the costs of those vehicles equipped with additional sensors, in comparison to operating a fleet of testing vehicles, the costs of additional sensors in customer vehicles is negligible.

Examples:
- Additional sensors in engine block for detection of combustion pressure
- Additional temperature sensors at wheel carrier to log temperature profile at brake disc

Benefit:
- Lower development costs

5.3.3 Improved Accuracy of Market Categorization

The automotive industry is developing for a global market with various local requirements. In addition to country-specific laws, automakers also consider external factors such as climatic, geographic and infrastructural conditions when offering their products in specific regions. This can result in a limited product range of vehicles or options and thus diminishing potential profits in certain markets. In other cases, based on the country specification additional components (e.g. larger radiators in hot countries) are required which increases the cost of each unit sold to this market. Furthermore, many functions and components are developed to be sold globally and hence the most extreme conditions (e.g. climate, road surface, etc.) will govern the design. In these cases, an accurate knowledge of the most extreme environments likely to be experienced by the vehicle is essential.
In the interviews the following use-cases were brought forward which could use customer data to get accurate and reliable country specification:

Examples:
- Customer-relevant classification of countries regarding their temperature exposure (super-hot, hot, normal, cold) based on ambient temperature reading from vehicle sensor
- Evaluation of maximum temperature and temperature histograms in certain areas of vehicle as input for material degradation
- Number of days with grid salt (approximated through temperature, wiper and GPS)
- What is the typical road surface quality?
  → Can large wheels be sold?
  Are protective measures necessary (sump guards etc)?

Benefit:
- Higher revenues
- Lower unit costs

5.3.4 Accelerated Development of New Technologies

Most interviewees mentioned the upcoming challenge of a disruptive change of technology from combustion engines towards electric cars with autonomous driving functions. As most OEMs don’t have extensive experience in these new fields of technology, being able to access data from customer cars is seen as very advantageous in regard to costs (reduced number of test vehicles operated by the OEM), speed of development (large amount of data produced in short time) and reliability (larger variety and number of data sets possible than from OEM-owned test vehicles).

Autonomous Driving:

Autonomous and semi-autonomous vehicles are seen as one of the big technology advances in the foreseeable future of the automotive industry. However, due to the novelty OEMs have only very limited experience with these advanced systems. OEMs will need a huge data pool of traffic scenarios as foundation for the implementation of safe and reliable autonomous driving assistants. Instead of generating these data with their own test fleets operated by highly paid employees, OEMs can generate a large amount of these data from customer vehicles for free. In addition, the verification of advanced driver assistance systems can, at least in part, be done with simulators using traffic situations of customer vehicles. This would reduce development costs, increase the development speed, reduce time-to-market and thus increase revenues.

Examples:
- Developing a data base of critical traffic situations based on data from customer vehicles (radar sensors, camera images, etc.)
- Testing and verification of driving assistance systems using data from customer vehicles
- Updates of driving assistance systems based on new scenarios from customer vehicles

Benefit:
- Lower development costs
- Higher revenues

Electric Cars

For most OEMs, battery electric vehicles are still a rather new technology and, until today, they have only limited experience with the new key-components such as batteries or electric motors. Using customer data from their first all-electric cars will give them the ability to develop this new technology quickly and reduce the risk of technical faults as well as customer annoyance in the future.

Examples:
- Number of loading cycles of a battery
- Typical charging behaviour of customers (state of charge when customers start charging, percentage of AC and DC charging)
- Positioning of charging stations etc. can be optimized based on real life customer data

- Based on data of vehicle cameras and parking sensors the optimum location for the charging plug can be established

Benefit:
- Lower development costs
- Higher revenues

5.3.5 Increased Understanding of Function on Demand Business Model

Large amounts of revenues in the automotive business are made through sales of options added to the base model. Typically, the margins are significantly higher on options than on the vehicle itself. Access to customer data can help OEMs understand the implications of different business models such as traditional sales of options and marketing of function on demand (FoD) services. With knowledge of the actual usage of certain functions, the OEM can evaluate whether sales of options or FoD will generate higher revenues.

Examples:
- Assessing how often different options are used by customers to evaluate whether classic option sales or FoD is more profitable
- Pro-active offer of FoD options if a certain situation is detected (fog lamps in bad weather conditions, cruise control if a long trip is planned)

Benefit:
- Higher revenues

5.3.6 Source for Communication to Customers / Additional Services

The access to data from customer vehicles will enable OEMs to understand the typical customer usage of a certain type of car. In addition, they will also gain a channel to directly communicate with each individual customer. This additional stream of information can be used to gain an in-depth knowledge of customers' wishes and thoughts or as an information and marketing tool.

Examples:
- Implementation of customer-feedback system into vehicle's infotainment system to give customer the ability to report faults etc. directly to OEM
- Purchase suggestions for fleet customers based on data of their own fleet vehicles
- Developing of quality score for each individual vehicle (based on the driving behaviour) to be used as proof of quality when selling the car

Benefit: - Higher revenues through increased market share

5.3.7 Development of Predictive Tools

Predictive maintenance aims at replacing fixed service intervals for inspections with a detection algorithm, which can forecast upcoming problems. While predictive maintenance is gaining popularity in the machine tool industry (Peng *et al.* 2010) there is no implementation of predictive maintenance or predictive failure alerts in customer cars yet. However, with access to data from customer cars, OEMs will have a large number of data samples to develop such predictive methods. While in the foreseeable future this will not replace fixed service intervals, it might give customers additional protection against costly repairs or safety critical damages.

Examples:
- Development of predictive maintenance systems informing customers to have components repaired or replaced before a failure would damage a more a costly vehicle part (e.g. replace oil pump before engine breaks down)
- Development of a guided maintenance system: if vehicle sensors detect an extreme driving situation (e.g. deep pot hole), during the next inspection the mechanic will get an automatic request to check or replace certain parts

Benefit: - Higher revenues through increased market share

5.4 Summary of Expert Interviews

In the interviews carried out for this study, automotive experts showed a keen interest in the possibility of incorporating data from customer cars into the vehicle development process. All experts agreed that a better understanding of customer usage would be beneficial for OEMs and could help developing vehicles with added user benefit with more accurate technical designs at lower costs. Based on their individual experience in automotive development, they identified numerous areas of development, which would benefit from access to data from customer cars. The use-cases relevant for development departments described in the previous sections could be categorized in seven different groups according to their major aim. Individual groups of use-cases consist of different possible applications. These have been evaluated regarding their potential benefits regarding revenues or cost structure (see Tab. 1).

The most relevant economic gains for an OEM were seen in terms of increasing revenues, reduced development costs and lower unit costs. A better understanding of customer wants will facilitate the development of features with higher customer relevance and can help to increase revenues in the future. At the same time, focusing development on functions relevant to the majority of customers and omitting functions with lower customer relevance can reduce development efforts substantially. With a better understanding of the driving behaviour and the conditions vehicles are used in, internal test standards can be based on hard facts rather than assumptions. This can help to avoid over-engineered designs and reduce the unit costs.

The vast majority of possible use-cases brought forward could be categorized in one of the following four groups of development aims and can be labelled as the most relevant aspects of customer data analysis:

- Development of functions with real customer benefit
- Adjusting requirements and test standards according to customer usage
- Improved accuracy of market categorization
- Accelerated development of new technologies

The first two development aims were brought up in each of the interviews conducted for this study and were rated as most promising in regard to economic gains for the OEM. All interviewees agreed that access to data from customer cars will facilitate the development with higher customer orientation resulting in vehicles with higher customer benefits. Products with additional value to customers are likely to increase OEMs' revenues through a higher market share. Seven out of nine experts presumed that some requirements and internal test standards have too high safety margins and lead to costly over-engineered designs. Analysing real driving behaviour and environmental conditions could help to reduce safety margins to a more appropriate level with direct consequences on costs. Another big potential for using customer data in in R&D was seen in the development of future technologies in which OEMs don't have a lot of experience yet. Here, Tesla's efforts in collecting data for the development of their advanced driver assistance systems was mentioned several times as an example. It was concluded that departments with access to data from customer cars can develop a larger pool of relevant data in a shorter time without the need to run a big and expensive fleet of test vehicles. In addition, four interviewees mentioned that analysing customer data could also help to increase revenues by overhauling existing or future business models. Especially evaluating market restrictions were seen as a simple way of increasing revenues without the need for technical changes.

Despite the generally positive view of the potential benefits the access of customer data could give development departments, two interviewees presumed that, despite the existence of hard facts, changing development guidelines will be difficult and will take long time. OEMs are careful when setting requirements below a previously followed level, especially if safety-relevant components are affected. Furthermore, if data from customer vehicles show the necessity of higher test requirements, OEMs will be liable to increase their standards, which most likely will result in increasing unit costs but might reduce expenditure for warranty cases.

Tab. 1: Overview of possible use-cases for using data from customer vehicles

Use-Case	Application	Examples	Benefit
Tailored development according to customer wishes	Counter of function utilizations	- Counter of how often a button is pressed	Lower Unit Costs, Lower R&D Costs, Lower Logistics Costs
	Prediction of wants from preferred settings	- Define suspension firmness according to preferred setting of customers with adjustable suspension	Increased Revenues, Lower Unit Costs
	Usability of Infotainment	- Assessment of operating errors (off target touch) in order to develop better ergonomics	Increased Revenues
	Trend scouting	- What do users search for when using the internet connection of the vehicle?	Increased Revenues
Improved accuracy of internal test standards	Usage counter / timer	- How often is the alternator in a hybrid car used?	Lower Unit Costs, Lower Warranty Costs
	Usage patterns	- How often is a vehicle used fully loaded?	Lower Unit Costs, Lower Warranty Costs
	Verification of extreme situations	- How often do misuse conditions occur?	Lower Unit Costs, Lower Warranty Costs
	Re-design of development models	- Re-design of test tracks to account for SUV-specific loading	Lower R&D Costs
	Customer test fleet with added sensors	- Additional sensors in engine block for detection of combustion pressure	Lower R&D Costs
Improved accuracy of market categorization	Country-specific restrictions	- Assessing the typical road surface quality in a specific country	Increased Revenues, Lower Unit Costs
Accelerated development of new technologies	Autonomous driving	- Developing a data base of critical traffic situations based on data from customer vehicles	Increased Revenues, Lower R&D Costs
	Electric cars	- Number of loading cycles of a battery	Increased Revenues, Lower R&D Costs
Increased understanding of business models	Function on demand	- Assessing how often different options are used by customers to evaluate whether classic option sales or FoD is more profitable	Increased Revenues
Source for communication to customers	Direct communication between customers and OEM	- Implementation of customer-feedback system into vehicle's infotainment system to give customer the ability to report faults etc. directly to OEM	Increased Revenues
Development of predictive tools	Predictive service models	- Development of predictive maintenance systems	Increased Revenues

Legend	
(icon)	Increased Revenues
(icon)	Lower R&D Costs
(icon)	Lower Unit Costs
(icon)	Lower Warranty Costs
(icon)	Lower Logistics Costs

6 Case Study: Using Customer Data in Automotive Durability Development

For a more detailed study of the opportunity big data can play when used as input for R&D, this chapter will discuss possible use-cases for an OEM's durability department. The author has five years of working experience in automotive durability development. Many aspects presented in the following paragraphs are based on this experience as well as on discussions with peers and colleagues. This case-study aims at giving a deeper understanding of the implications and the technical considerations to be considered when implementing a system feeding customer data into an OEM's development department. In comparison to the broader discussion of possible use-cases in the previous chapter, this section focuses one a narrow field of application and has a more technical approach.

Typically, a durability department is responsible for load data acquisition during the development process of a vehicles which requires handling and processing of large amounts of data. A fundamental understanding of handling big data volumes is already existing in these departments. Furthermore, many assumptions made during durability development define the determining load case for several components which directly affects their price. Thus, a durability development can be seen as a promising area to introduce data analysis of customer vehicles.

In the first section of this case study, the fundamentals of durability and fatigues are presented. This is followed by a brief summary of the tasks done within an OEM's durability department throughout the development of a new vehicle. Based on this information, the effect of durable design on costs is discussed, durability-related use-cases for using customer data are evaluated, and different technical solutions for data acquisition and data analysis are compared.

6.1 Ensuring Long-Term Quality in Automotive Development

The assurance of a trouble-free usage of a vehicle over a prolonged time duration is for most customers more important than design, purchasing price or fuel economy (Schönleber & Trede 2008). Thus, OEMs have a huge interest to ensure a consistent high quality and long-time reliability of their products, and thereby invest in their brand's reputation. Long-term reliability of a vehicle is determined by different influencing factors OEMs need to consider (Ungermann 2009):

1. **Design Quality**

   All components of a car have to be designed in a way, that they will sustain all expected loads and environmental conditions over its designated lifetime. Additionally, the design should incorporate a certain degree of robustness against non-intended use or misuse of the vehicle.

2. **Production Process Reliability**

   Reliable build quality is the main influencing factor for early failures. An early breakdown could for example be caused by a hose clamp, which has not been fixed correctly during assembly. However, other quality issues during production can have an influence on the long-term durability. Thus, a consistent build quality has to be ensured and monitored through feasible quality assurance measures over the entire production chain.

3. **Material Quality**

   Another cause for a vehicle's non-satisfactory long-term performance is poor quality of raw material or supplier parts. This can range from sheet metal as seen during the 'Lopez era' at Volkswagen in the 1990s (Wimmer & Muni 2011) to recalls due to wrong bolts in Tesla's power steering system supplied by Bosch (Hull 2018). Strict quality assurance measures along the entire supply chain are necessary to minimize this cause of premature breakdown.

While the first variable influencing poor long-term quality is governed by R&D, the latter two factors have to be accounted for by feasible measures implemented during pre-production phase and then monitored during serial production by quality assurance and production departments.

During the development process of a vehicle, the long-term reliability has to be considered in every development step for each component as well as for the entire vehicle. The goal is to ensure a sustained high level of customer experience and breakdown-free service life. Typically, special departments responsible for durability, corrosion or thermal degradation assist component developers within the OEM's R&D centres to incorporate a durable design from an early stage of development.

6.1.1 Durability and Fatigue – A Statistical Challenge

In engineering the term *fatigue* is strongly related with August Wöhler who was one of the first scientists who, following a train accident in 1875 which had been caused by a broken wheel, studied the effect of repeated loads on the structural integrity of metals. (Pook 2007). In short, fatigue describes the phenomenon that repeated loads well below the material's ultimate strength (and even within the materials elastic regime i.e. below the yield stress) can ultimately cause catastrophic failure. This behaviour is commonly described by the formation and propagation of micro-cracks within the material (Halford 2006). The number of load reversals is determined by stress level, the material and the component's geometry (e.g. stress concentration due to shar notches etc.) (Pook 2007). A commonly used method to describe the effect of fatigue is the S-N curve (also called Wöhler-curve) developed by August Wöhler describing the decreasing number of load cycles until structural failure with increasing stress levels.

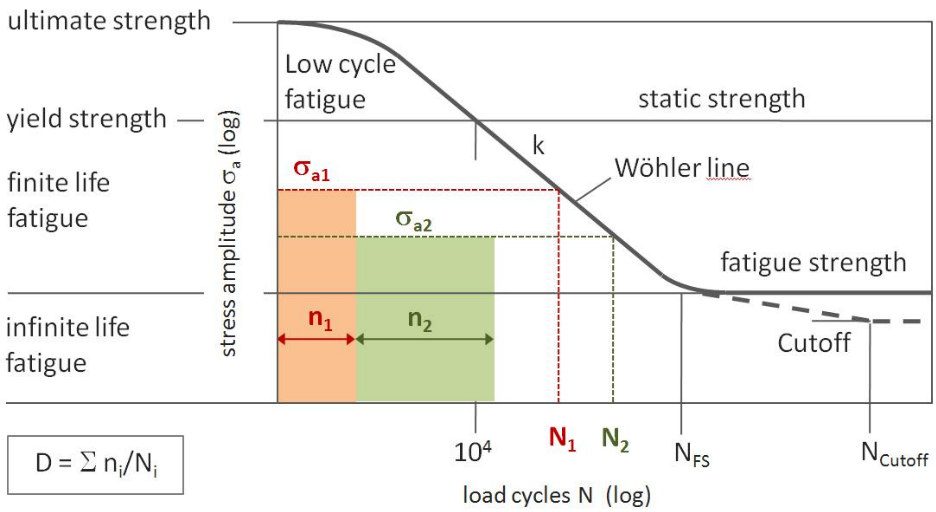

Fig. 11: Typical S-N curve (Wöhler curve) describing for different stress levels σ_a the number of load cycles N until failure (Homan 2018).

S-N curves for a certain material are typically established using standardized specimens and constant stress levels. However, when looking at the durability of real components from as serial production, a certain variation of fatigue strength will be seen. This can be caused by variation of material quality, geometry tolerances or divergency of production parameters (Ungermann 2009). In addition, the vehicle loads will vary largely between different drivers in different regions. To guarantee a safe and reliable performance over the expected service life, even the combination of "bad" parts with a low fatigue strength and high loads induced by driving style or road conditions have to result in a satisfactory durability.

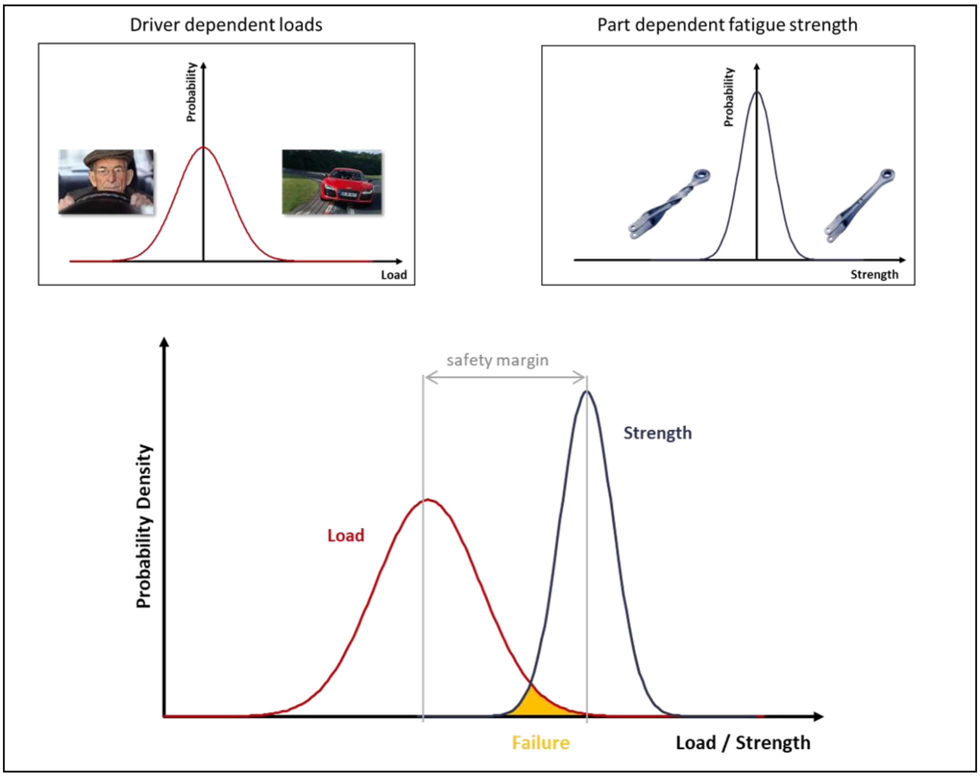

Fig. 12: Statistical problem of expected loads and real part fatigue strength: the yellow area below the intersection of the curves has to be avoided to ensure long-term reliability.

6.1.2 Durability Design Philosophy at AUDI AG

At AUDI AG the durability department is responsible for all load and temperature related degradation processes which might alter a vehicle's long-term performance. This includes load data acquisition in the early stage of development, deriving feasible requirements for component design and testing, as well as verifying the durability of single components, assembly groups and entire vehicles in a later phase. The assessment is based on three different loading scenarios (Hammer & Ehrich 2015):

1. **Typical Use**

   Usage in accordance with the product specification. Load data consists of typical service loads, which a vehicle will experience during on-road usage over its life-time. Design loads are derived from load data acquisition of the particular vehicle on standardized test tracks representing an anticipated usage of typical customers. A failure is not accepted before the intended life-time mileage of 300,000 km or 15 years usage time. To account for variations in part quality and driving behaviour (see Fig. 12), a statistical approach is used to represent a combinations of the 1%-driver (the driver from a group of 100 people who produces the highest resulting loads in the vehicle) and the 1‰-part (part with the lowest fatigue strength out of a lot of 1.000 produced parts) (Ungermann 2009, Hammer & Ehrich 2015).

2. **Foreseeable Misuse**

   Usage consisting of single high load events, which mark the upper limit of the intended use. These situations are not in accordance to the product specification but can occur several times during a vehicles service life (e.g. driving through potholes, emergency breaking on cobblestone roads, etc.). Damage is not acceptable, and all components still need to fulfil the durability requirements afterwards.

3. **Abuse**

   Abuse is defined as situations beyond the limit of the intended use but below a situation considered a crash. Examples are hitting the curb with a wheel or driving over a speed bump with excessive speed. Structural damage is allowed but must not lead to dangerous situations or exorbitant repair costs. In accordance to the AUDI guide lines in regard to durability, it is of uttermost importance that no *sudden* structural failure occurs. The design philosophy “Leak before Break” is applied which means that no hidden damages or cracks are allowed to occur without a customer being able to identify a problem before a catastrophic failure of a part. Thus, damages due to abuse are acceptable if and only if the damage is recognizable for the driver. For example, a misaligned steering wheel, distorted wheels or contact noise would be a clear indicator for customers to see a service centre. In contrast, a bending or cracking of a control arm without a recognizable misalignment of the wheels or the steering wheel are not acceptable (Hammer & Ehrich 2015).

Fig. 13: Pothole misuse test (Weber 2009)

6.1.3 From Load Data Acquisition to Component Requirements

An OEM's durability department derives load data requirements and test requirements for individual parts as well as the entire vehicle. Typically, the foundation for these requirements are OEM-specific specifications which are derived from different mileage requirements on certain test tracks each representing specific operating conditions a car might experience during its service life. At AUDI AG the durability requirements for passenger cars are defined as 300,000 km and 15 years of use by the most critical driver of 100 ("1%-driver"). Since the profile of the used test tracks represent only relevant loading conditions, 300,000 km in customer hands can be simulated by 100,000 km customer-realistic driving on "Wechselkurs", 8,000 km driving on roads inducing high vertical loads on "Schlechtwegekurs" or 30,000 km high-speed testing (Ungermann 2009).

Fig. 14: Examples of different road sections on Audi's "Schlechtwegekurs" test track (Ungermann 2009)

By leaving out situations which do not contribute to a load induced fatigue (e.g. traveling with constant speed on a straight road with smooth tarmac) these accelerated testing conditions allow to finish a test representing a vehicles entire lifetime within a few weeks.

To derive load requirements, vehicles equipped with various load data transducers measure the vehicle loads resulting from the road surface excitation along a few laps of these test tracks or during misuse and abuse tests. At the development start, when no prototype vehicles are yet available, these loads are acquired by mathematically extrapolating data from predecessor models. These loads are then updated during the development process when prototype vehicles are available. From measured data, the vehicle requirements for the service life can be extrapolated.

Component requirements are derived from vehicle loads through computer simulations using finite element or dynamic mechanicals analysis software.

6.1.4 Fatigue Testing

Fatigue requirements are monitored throughout the different stages of automotive development. As in many other industries such as aerospace or software design, tests are conducted according the so called “testing pyramid” on different levels of integration. Starting from material testing, fatigue tests are conducted on components, sub-assemblies and entire vehicles.

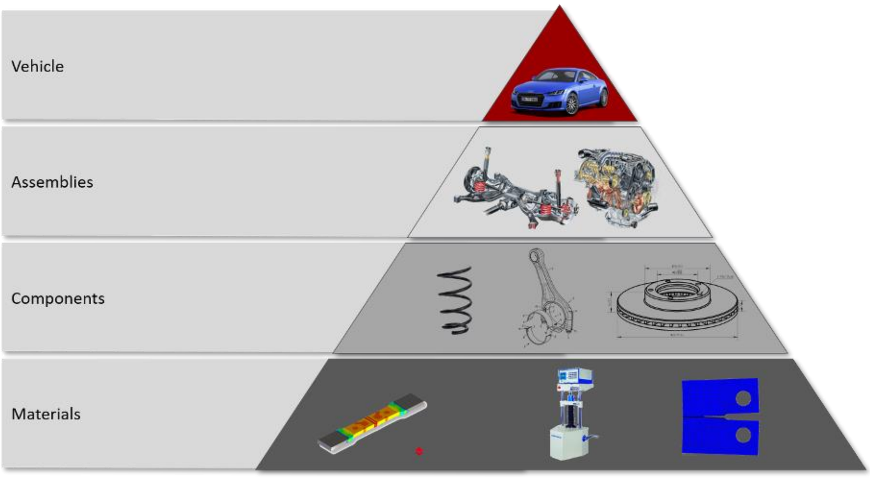

Fig. 15: Testing pyramid in automotive development (Hammer & Ehrich 2015)

Typically, fatigue tests on different levels of integration are carried out using costly hydraulic test beds with varying degrees of freedom (DOF). While components with a simple geometry and singular loading characteristic can be tested uniaxially using just one actuator, components which experience a multitude of different loads in the vehicle require testing with various hydraulic cylinders introducing loads simultaneously. Vehicle testing can either be done by driving on a test track or on a “road simulator”, a testbench introducing six DOF on each wheel by hydraulic actuators.

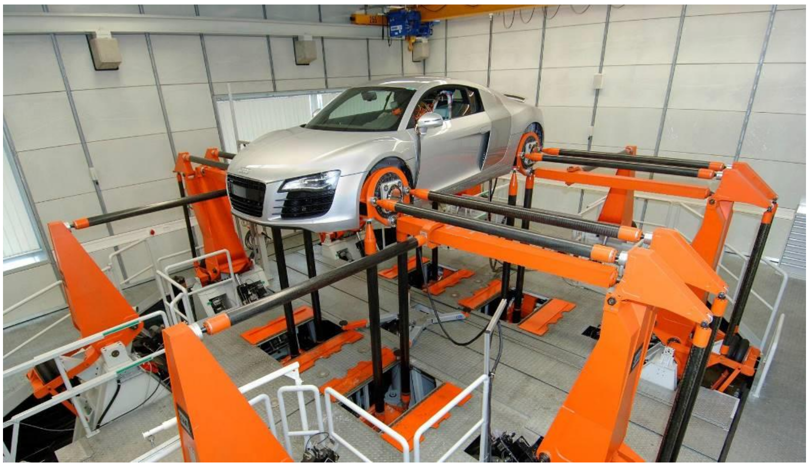

Fig. 16 Road simulator at AUDI AG (Hammer & Ehrich 2015)

While on-road testing is closest to real life, using costly test beds allow to carry out tests in an early stage of development without risking health and safety of test drivers. Additionally, tests can be carried out regardless of weather conditions or influence due to driving style. Environmental factors such as corrosive mediums (e.g. grid salt), temperature or humidity can have a significant effect on a component's fatigue behaviour. This is not only relevant to corroding steel parts but also to aluminium components which experience a substantial reduction of fatigue strength under the influence of saline solution (Duarte de Araújo *et al.* 2018) or elastomers which deteriorate in the presence of high temperatures (Mars & Fatemi 2004). Thus, for a realistic evaluation of a vehicles fatigue behaviour, these factors need to be and can be accounted for when testing components or assemblies using specialized test beds.

6.1.5 Misuse & Abuse Testing

The non-linear behaviour and the complex interaction of various parts during a high load situation limits the ability to test single components for their durability in such scenarios. However, maximum loads and aspired yield loads of individual parts (e.g. established during vehicle tests using strain gauges) can be monitored on component level. In later development stages, vehicle tests are carried out to verify the durability in misuse and abuse situations. These tests are very expensive since prototype vehicles can cost several hundred thousand Euros. After a series of tests, these cars are likely to exhibit sever damages; especially in the early phases of development.

When it comes to high load testing such as misuse or abuse scenarios, the main focus is on passenger safety. While certain damages are unavoidable depending on the situation, no hidden damage, which could impair the car's safety or a component's fatigue behaviour is acceptable. By following this philosophy, a sudden defect of a safety-relevant part at a later date following an abuse situation, for example during high-speed travel, should be eliminated. Thus, the vehicle system should endure misuse loads without major damage but should exhibit strong deformations to certain parts above that load level to make the damage apparent to the driver. This discrepancy can be solved by developing chassis control arms with distinct yield loads which exhibit a large deformation above a certain threshold. However, this is a difficult task and is limited to a limited number of load cases. Thus, during the development process it is regularly questioned whether a certain deformation can be classified as customer-recognizable.

6.2 Durability Requirements – From the Past into the Future

Current requirements which set the basis for the durability development of a car have been developed by OEMs over several decades of automotive development. In their core, they are based on assumptions and empiric experience gained throughout several development cycles. Usually they are extended or adapted if a new failure type is experienced during development or even worse from customer defects. Thus, by now they ensure a high level of long-term quality and safety. However, even if today's standards seem to prevent premature failure and safety relevant defects, until today there is no data which documents how relevant the test scenarios under real conditions in customer hands are and whether certain requirements are exaggerated.

Furthermore, durability requirements are based on experience gained in the past. They are not necessarily a trustworthy basis when it comes to changes in the future. These changes can include new markets with different customer behaviour as well as changes of technology. An example of the past is the tow bar: when bike racks for tow bars were introduced, the requirements of this simple component had to be changed completely as the loads from a bike rack oscillating on the tow bar are completely different from towing a trailer. Even more sever changes can be anticipated with the introduction of electric cars or increasing autonomous features. With increasing self-driving capabilities, a reduction of high loads due to potholes etc. can be anticipated.

6.3 Cost of Durability

Long-term reliability is an important aspect for customers and is a major contributing factor for brand reputation and customer loyalty (Schönleber & Trede 2008). This reputation is built over time and is very valuable for a brand, although difficult to quantify. However, just a few issues with the long-term quality are enough to seriously jeopardize customers' trust into a brand. Thus, OEMs can't afford to trifle with durability. At the same time cost pressure is pervasive in automotive development which leads to the question "how much needs to be done to ensure long-lasting quality without exaggerated costs due to over-engineered solutions and overspending on testing?" The damaging effect of low reliability on a brand's reputation is difficult to quantify. However, it can be presumed that the loss in sales due to lower brand loyalty is more substantial than the earnings from sales of spare parts due to premature failures (not included profits from wear parts such as brake pads or shock absorbers).

According to (Ungermann 2009), the following cost factors directly related to automotive durability have to be accounted for: testing costs (increasing costs with more intensive testing) and warranty costs on the one hand and profits earned by sales of spare parts on the other hand. To find an optimal economic solution, the sum of this triad has to be minimized (Ungermann 2009).

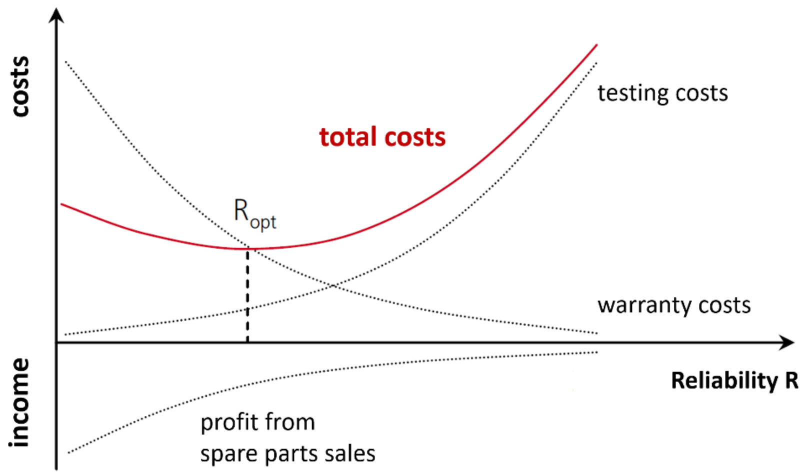

Fig. 17: Cost optimal solution for vehicle reliability according to Ungermann (Ungermann 2009)

However, there are other cost factors for an OEM which are related to a vehicle's durability. Most importantly for many OEMs is the unit price of each component. Durability requirements directly affect the price as well as weight of every relevant part by setting the mechanical specifications. Consequently, exaggerated durability demands can lead to over-engineered solutions, which increase a vehicle's price. In addition, an over-engineered design results in a higher component weight. In a secondary effect, this could also mean a price and weight increase of other components, which have to support the added weight.

Another important cost factor related to durability related considerations are restrictions to the product range and option lists in certain market regions due to anticipated road conditions or environmental factors. A typical example is a region-specific restriction of large option wheels, which are a highly profitable option for OEMs, directly reducing the profit made per car. In certain markets special provisions such as additional corrosion measures or undercarriage protectors are applied to every vehicle sold. Decisions on product range restrictions or the necessity for additional robustness measures are made based on feedback from local importers and service stations, analysis of spare part sales, and on-site inspections through special OEM-teams. Access to customer data could help to verify the existing market classifications and adjust them if necessary.

Thus, for a cost-optimal durability development, durability requirements developed over the years have to be questioned and overhauled regularly to ensure a high level of long-term quality and safety without running the risk of developing costly and over-weight designs or limiting the sales of potential *cash cows* without necessity.

6.4 Technical Consideration of Customer Data Analysis

Due to the high number of sensors used during data acquisition campaigns of vehicle load data, durability departments are typically well equipped to handle large data sets. However, feeding back data from tens of thousands of customer cars into the data collection systems of a durability department would exponentiate the amount of data to an extent that the way of data processing done so far would immediately reach its limits. Thus, handling of customer data needs to be done entirely different from the data recording principles used so far with test vehicles. There are different techniques to reduce the amount of data each customer vehicle feeds into the OEMs data system. The more data processing is done in-situ within the vehicle's ECUs, the smaller the data quantity transferred to OEM servers. However, for data processing within the vehicle, ECUs with enough computing power are necessary in each vehicle, which directly increases the unit costs. Thus, there will be a trade-off between spending money on computing power within the vehicle and the amount of data transferred. In addition to the cost factor, the decision which kind of data quality (raw sensor data or pre-processed results) will be transferred depends primarily on the problem to be solved. While counting utilizations of a certain function can be easily done within the vehicle, analysing complex traffic situation will most likely be done on OEM servers.

6.4.1 Fixed Implementation vs. Test Campaign

When it comes to the implementation of data collecting functions in customer vehicles, there are two options in regard to the predefined time frame of operation.

Fixed Implementation

A fixed implementation of data collection will be unchanged for the vehicle's entire lifetime. Thus, the data collection system will be programmed only once, and the code will be implemented unalterable on the vehicle's ECU. Since the type of data transferred to the OEM stays the same, the back-hand server which will receive the data from customer vehicles is also programmed only once. This will reduce the effort during data collection significantly as the system will be stable once it is implemented. Although the number of data sets will increase over the years, it is questionable whether this continuous increase of data volume will give additional value. It can be assumed that for most applications a certain amount of data sources is necessary for a valid analysis. However, once this threshold is reached, additional data is giving only limited surplus of information.

Test Campaign Implementation

When implementing test campaigns for data collection, the data collection implementation on the ECUs of customer vehicles is only temporary. Thus, the computing power of the ECU is used successively for different data collecting applications. This means that both, ECU implementation and back-hand software need to be re-developed for each test campaign. As a benefit, this kind of implementation collects data only as long as additional data points are necessary for the analysis. Once the analysis of a certain problem is finished, a new project can be installed on customer vehicles. Thus, computing power of the on-board vehicle hardware is used more efficient.

6.4.2 Data Selection Models

Before data from customer cars is analysed, an algorithm has to choose a relevant data subset to be analysed. This selection process is based on a pre-selection model, which has to be implemented prior to the data collection process. In a simple counting or data classification model, the pre-selection model monitors the sensor data which will be classified and add to the existing score every time the data value exhibits a certain threshold. More complex pre-selection models analyse several data channels simultaneously and can, depending on the situation diagnosed, select different data channels for transfer. Transferred data can vary from scalar values to real-time data traces for a pre-defined period of time. With the availability of big data sources, pre-selection models can be developed based on self-learning algorithms. Models based on these advanced techniques are more reliable to distinguish complex situations from each other than analytical models defined by engineers based on their observations (see Fig. 18). The quality of the selection model defines the outcome of the data collection program!

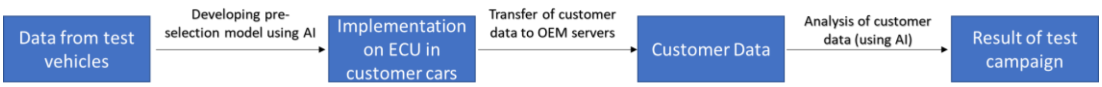

Fig. 18: Implementation of artificial intelligence (AI) into customer data collection

6.4.3 Data Collection Models

The choice of the data collection method depends primarily on the problem to be solved. While simple utilization counters are predestined for in-situ processing, more complex data processing is better be done outside the vehicle on a server. In both cases, a pre-selection algorithm defines which data is selected for further processing and which one can be neglected. Once a significant event is detected by the pre-selection model, there are various ways of data handling:

Event Counter

An event counter increases the current counter value by one every time the pre-selection model detects the situation which is to be analysed. The result of this method is a number, which increases every time the observed situation is detected. Over time the data size of the result stays constant; only the value of the counter rises.

Examples:
- Number of times a button is pressed
- Number of times an emergency brake is detected
- Number of times a pot hole is detected

Data Histogram

Similar to an event counter, data histograms add a one to the current value of the respective counter if a certain situation is detected. However, in contrast to a one-dimensional counter they classify the data in pre-defined value groups (see Fig. 19 as an example). Consequently, the resulting histogram shows how often which kind of situation takes place. This modelling approach is useful to differentiate and quantify the occurrence of the same situation with varying data values. Similar to an event counter, the data size will stay constant while the individual values will increase over time. Due to the limited computing power necessary, data processing can be done on the vehicle’s ECU and the resulting values of the histogram are transferred to the server.

Examples:
- Classification of ambient temperature
- Classification of situations with high vertical acceleration
- How often is how much torque delivered?

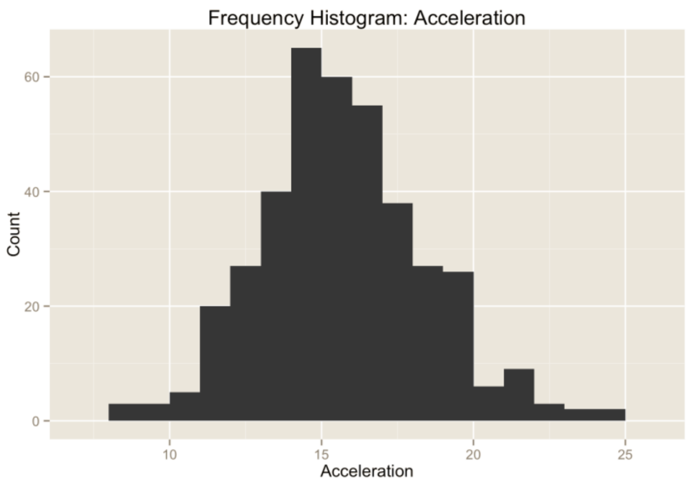

Fig. 19: Example for a histogram displaying the number of accelerations exceeding a certain threshold value (Smith 2016)

Time Frame Selection

With more complex problems, scalar values given by event counters or histograms are not sufficient to fully analyse the situation. Thus, the data volume transferred to OEM servers increase significantly and a careful pre-selection model is crucial to be able to handle the amount of data. If the pre-selection model is triggered, the traces of pre-defined sensors are collected for a pre-defined period of time. Depending on the situation detected by the pre-selection model, data from different sensors can be collected. Depending on the implementation, data points before and after the trigger of the pre-selection model can be transferred. The sensitivity of the selection model as well as the time duration of data recording, and the choice of sensors (number and types) define the amount of data. In contrast to event counters, the data volume on OEM servers increase with increasing number of vehicles and increasing duration of data collection campaign.

Examples:
- Wheel spin irregularities after detection of high-velocity speed bump pass-over
- Video data from outside facing cameras in the event of autonomous driving functions detect irregularities

Full Trace

A full trace of certain sensors transfers life data from the vehicle to the server. In motorsport life-monitoring of crucial components through the telemetry systems of modern race cars is in common use throughout the race. However, due to the huge amount of data this kind of monitoring is not feasible for data analysis of customer cars.

6.5 Possible Use-Cases for Customer Data Analysis in a Durability Department

Many assumptions made to ensure vehicle durability are defining the technical design of crucial components and consequently directly affect their price. Thus, a more profound understanding of vehicle use of real customers could help to adjust relevant test scenarios and reduce costs. In the interviews carried out for this study, several interviewees named different use-cases for the application of customer data within the durability department; even though many of them work in entirely different fields of automotive development.

The use-cases brought forward are presented in the following; clustered according to the different fields of durability.

6.5.1 Use-Cases for Fatigue Requirements

Fatigue requirements are defined on the vehicle level and can be transferred into fatigue requirements of individual components. They are some of the key-requirements put down in the specification sheet in the beginning of the development and have a strong impact on the final design of each component. Typically, vehicle requirements are derived from pre-defined test tracks representing different kind of road surface and road types (motorways, country roads and city roads). Further, assumptions regarding the loading situation of the vehicle (percentage of road use fully loaded vs. with just one occupant) or the number of emergency braking have an impact on the fatigue requirements. The following use-cases for using customer data could help to improve the assumptions made for automotive development.

Vehicle Weight Assumption

The vehicle weight directly affects the service loads in the car body, chassis and drive train. Assuming a fully loaded vehicle for its entire service life is not very realistic and would result in an over-engineered design in various components. However, a realistic assumption of the loading situation is difficult. The analysis of customer vehicles could result in an approximation of how much percent of the mileage is driven with how much gross load weight.

Since there is no sensor for measuring vehicle mass, the loading of the vehicle needs to be estimated with a suitable model based on accelerations, engine power and suspension travel. Once such a model is verified, histograms with mileage over vehicle weight can be established giving the durability department the ability to set feasible loading scenarios.

Race Track Detection

Vehicle use on race tracks amplifies the vehicle loads by several magnitudes. Thus, if a considerable amount of the mileage over the life-time of a car is done on a race track, this significantly affects the durability requirements. For OEM it is very difficult to come up with feasible assumptions regarding race track usage. Consequently, during the interviews carried out for this study, one OEM was named who introduced a system for customer data analysis mainly in order to detect race track usage. A race track detection can be done based on GPS data and vehicle accelerations. A simple event counter approach logging the mileage on a race track is sufficient to give OEMs a clear understanding.

Steering Angle Analysis

For several components in a vehicle's chassis and suspension system, the steering angle distribution over service life is determining the technical design (e.g. rubber mounts, air suspension struts). Today, the steering angle distribution is a consequence of the test tracks used to determine the vehicle's durability requirements. However, if a vehicle is used primarily in city traffic, larger steering angles can be assumed than during use on motorways. Using a histogram approach, the number of situations with steering angles exceeding certain thresholds could give a sound picture of typical use as well as worst case scenarios.

6.5.2 Use-Cases for Misuse and Abuse Requirements

For many components loads from misuse and abuse scenarios rather than from fatigue analysis are the defining parameter in the design process. Thus, the assumptions made regarding possible misuse scenarios have a strong influence on weight and costs of relevant components. At the same time, a realistic expectation of possible extreme situations and a safe failure behaviour of critical parts ("leak before break") is mandatory to ensure vehicle safety. The analysis of customer data can help OEMs to find optimal solutions regarding costs and safety.

Misuse counter

The assumptions made regarding foreseeable misuse and abuse scenarios have a huge impact on the design of safety-critical parts. Over the years, OEMs have accumulated numerous different misuse tests. While insufficient tests conditions would be noticed through warranty claims and accident reports, it is difficult to confirm whether the assumptions are realistic or excessive. With a data from vehicle tests, a detection algorithm that can recognize certain misuse situations could be developed based on accelerations, suspension travel, etc. This algorithm could be implemented on customer cars to evaluate the number of occurrences and the severity of different misuse scenarios. The data of such a misuse counter could enable a durability department to review their test procedures and make modifications where necessary.

Misuse Warning

In the development of safety critical parts, no hidden damages or cracks resulting from misuse or abuse scenarios are allowed to occur without a customer being able to identify the problem ("leak before break"). A reliable misuse detection algorithm could be used to give customers a warning in case of a high load event has been detected. Depending on the severity, a customer could be advised to see a service station or to stop the car immediately. Such a warning system would improve passenger safety and would reduce the necessity of developing complex parts with high deformations as indicators for critical loads. Thus, development costs could be reduced without compromising passenger safety.

Guided Maintenance

With connected cars, the results of a detection algorithms for high load events could also be used to organize an appointment with a service station and inform the mechanic about potential damages in certain components.

6.5.3 Market Restrictions

For durability of chassis components, the size of wheels is of high importance. With increasing diameters of rims and resulting decrease of tire wall height, road-induced chassis loads increase. Thus, in regions where road conditions are considered to be poor, large wheels are not sold as options resulting in a reduction of potential profits. With access to customer data, region classifications regarding road conditions can be based on a large data base rather than on feedback from local importers or on-site inspections through special OEM-teams. Such a system would not only give information of the road quality but also about which kind of roads and regions customers in certain countries typically use. Thus, for different brands or different vehicle categories different restriction could result.

6.6 Summary: Customer Data for Durability Development

The requirements used in an OEM's durability department have been developed over the last decades of vehicle development and are intended to ensure long lasting quality and safety for the intended use as well as the foreseeable misuse of a vehicle. Statistical models are used to account for combinations of low quality parts and high loads, which are required to sustain the minimum requirements without premature failure. Requirements representing fatigue loads as well as extreme loads scenarios are important input parameters for the design of relevant components and are a major factor defining weight and costs.

In the definition of durability requirements, many assumptions regarding typical use of a vehicle are made. This includes many factors such as vehicle weight, road type, or misuse scenarios. With the ability to access and analyse data from customer vehicles, test requirements can be carefully assessed and, if necessary, adjusted according to the real customer usage. Especially with misuse test requirements, even small modifications can have a significant effect on component design and in consequence on unit cost. Moving from assumption-based requirements to data-based requirements, a more precise definition of test standards can be realized. Those requirements which are proven to be excessive compared to real customer usage can be reduced while new requirements might be defined to account for situations not accounted for so far. Thus, a more customer-oriented durability development can reduce costs and increase quality in those areas important to customers.

Due to intensive test campaigns for load data acquisition, durability departments are accustomed to work with large amounts of data. Although handling of customer data is a different scale of data volume, many data analysis methods can be carried over or developed further to monitor data from customer vehicles. Already simple counting methods, which produce only small amounts of data and require negligible computing power, will help to develop more realistic test requirements. The type of data harvesting technique implemented on customer cars will depend primarily on the individual use-case analysed.

7 Conclusion

Big data and connected cars is one of the trends valued most important for the future of the automobile industry. Current vehicles have hundreds of sensors all producing a huge amount of data and with increasing autonomous features it is likely that this number will increase dramatically. Today, most of these data are only used in-situ by certain vehicle systems and are discarded straight after they have been used. However, cars could potentially share such data with OEMs via mobile data networks. Already, some OEMs use the ability of connected cars to transfer customer data back to their own servers and in the literature, there are plenty of potential business models based on the usage of vehicle data. The majority of those business models aim at generating direct revenues through selling customers additional services similar to business models aiming at customers of mobile devices and online services. So far, most OEMs have limited their efforts in making profits from customer data to data bartering. This means, OEMs give third party companies access to the data of their customers to generate additional value; probably because there is not enough in-house experience of producing revenue from data rather than form selling hardware. Except Tesla, no other car manufacturer has openly announced to use data from customer vehicles in their development of future automobiles. In contrast to other forms of usage of customer data, in this field Tesla sets an example of transparency with giving customers the possibility to opt-out through an easily accessible button in their car's infotainment system without restricting any other features.

There are substantial regional differences when it comes to the legal framework, which OEMs have to take into consideration when transferring and analysing data from customer vehicles. In the USA there are, except for use by authorities, hardly any legal regulations of data collection and vending of data to other companies. For the automobile industry there is a self-regulation policy in place which, however, is rather vague in its formulation. In Europe much stricter legal limitations are in place. Especially since the GDPR legislation entered into force in May 2018, European citizens' privacy is protected by a powerful data protection act. This includes a *privacy by default* implementation which requires customers to actively opt-in before their data can be collected.

Customers seem to be used to their private data being collected and analysed by corporations such as Facebook, Google or Microsoft. Thus, many customers are not too concerned about their vehicle data being transferred to automotive companies. The willingness to share their data increases further, if drivers are assured that their data are not passed on to third parties and are only used for the purpose for which consent has been given. Under these circumstances three out of four vehicle owners would be happy to share their data with OEMs for technological improvements of future vehicles. Thus, customers' privacy needs don't seem to be a major roadblock for using data from customer vehicles for an improved vehicle development. However, OEMs have to be aware that any malpractice in the field of handling of personal data can have disastrous effect on their own brand image as well as on the willingness of customers to share their data in the future. In this context, Tesla's practice of publishing data from vehicles involved in a crash without prior permission by the vehicle owner or their relatives could impede access to data from customer vehicles for the whole industry.

Although big data is one of the well-known future trends in the automotive industry, many development departments at OEMs might not be aware of the possible benefit of customer data interpretation in their respective field of work. Due to the vast amount of data being produced by customer cars, a pre-condition for working with customer data is a sound pre-processing using adequate big data analysis methods. Once data from customer vehicles are concentrated and clustered according to the respective problem, they could become a valuable source of information for automotive development. In this study, the potential of using user data as input variables in various R&D departments of an OEM has been discussed with nine experts working in the automotive industry. They agreed that access to data from customer vehicle will help to develop vehicles tailored to customer needs and to their typical vehicle use. In total seven groups of use-cases could be identified which would profit from introducing customer data as input variables. The majority of the use-cases developed in this study aim at one of the following improvements of automotive development:

- **Better understanding of customer wants**
  A direct feed-back loop from customer data will enable OEMs to focus their development efforts on systems which customers use regularly. This will lead to a more customer-oriented development with more favoured products.
- **Better understanding of customer usage**
  By gaining a better understanding of customer usage, OEMs can refine their requirements and test procedures they developed over time. Big data will

help specifying more realistic requirements, which can reduce over-engineered solutions or reduce warranty costs. Furthermore, a more realistic understanding of customer behaviour or vehicle usage in different markets can reduce existing portfolio limitations in certain markets (e.g. large option wheels, which are very profitable, are not offered in certain markets due to existing road conditions).

- **Accelerated development of new technologies**
  Having access to a large pool of real driving data from customer cars will reduce the need of generating vehicle data through test campaigns and will ultimately speed up the development of technology; especially in fields which are still new to OEMs and where they have no extensive experience yet (e.g. autonomous driving).

All use-cases brought forward were analysed regarding their impact on the OEM's economic situation. Among the experts interviewed for this study, there was a general agreement, that the introduction of customer data as input for development could potentially increase revenues through products with higher customer benefit and at the same time reduce development effort and part costs. However, whether a system to incorporate customer data into vehicle development results in a positive business case cannot be answered in general. This depends on the particular use-case as well as the technical and operational realization.

For a detailed discussion of customer data analysis in automotive development, a case-study focusing on an OEM's durability department was chosen. Technical requirements set by an automotive durability department have direct effect on component costs. At the same time, many input variables are dependent on the vehicle usage and is not known to the OEM. Thus, in durability development there are several assumptions regarding customer behaviour, which directly affect the costs of numerous components. Even cautious reductions of certain specifications could reduce the costs of ever vehicle produced significantly. This might be the reason why several OEMs have started their customer data analysis program within their durability departments. However, as the numerous possible use-cases brought forward in the interviews show, there are plenty of other development departments, which could benefit from a better understanding of their customers.

Despite all advantages of customer data analysis, changing development standards, which have been used for decades will be difficult, even with customer data as hard evidence. There will be a large amount of data necessary to convince engineers to change their standards developed over many years of automotive development. The usage of customer data for developing functions with higher customer relevance is expected to see less opposition as there will be fewer reservations regarding premature faults and possible safety risks. Similarly, the introduction of data sets from customer vehicles in the development of autonomous driving systems is very likely. The access to a vast pool of data can reduce the development costs significantly and at the same time increase the safety and reliability of the systems due to the large variety of situations recorded.

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A.1 Interview Request

The following summary of the research topic including some preliminary questions was sent to all interviewees prior to the interview:

> Dear participant,
>
> thank you very much for taking your time to read the following introductory paragraph which will hopefully give you a better understanding of the subject I would like to discuss with you.
>
> For my master thesis I study how automobile manufacturers could improve their vehicle development by using data from customer cars. Already, many OEMs have introduced connected cars to the market and their capabilities regarding data transfer between vehicles and OEM servers will most likely be intensified in the upcoming years. There are plenty of studies discussing the potential earnings from new digital services based on connected cars. However, in my study I want to look at the traditional developing process within an automotive company and try to establish how the ability to know what customers exactly do with their cars could alter the way vehicles are developed today. A better understanding of user behaviour could alter vehicle development in many ways; from re-thinking development standards which are based on experience of pervious development projects to removing certain features altogether because customers don't use them. There might be numerous applications for customer data within an OEM's development process and with your help I would like to establish which departments could profit from them.
>
> I would like to discuss these matters with you in a short interview, to understand your standpoint in regard to this topic. Your answers will be anonymized and I will not ask for specifics of your company or details of your work. Both, your expert knowledge in your field of works as well as a general view on automotive development will be a valuable input for my work. I would appreciate an open mind on your behalf and creative suggestions in which departments and for which use-cases customer data could be of use.
>
> As a preparation, you will find a short list of basic questions. These are only a guideline and it's OK if you are not willing to answer all of them. Even a short brainstorming of potential use cases would be of great benefit.
>
> 1. In which field of vehicle development do you work at the moment?
> 2. Have you worked in a different field of vehicle development before? If yes, please specify.
> 3. What kind of input data do you need in your field of development?
> 4. What is the origin of input data for your work (internal standards, legal requirements, measurements, etc.)?
> 5. On what basis are requirements defined?
> 6. Brainstorming: which department of an OEM could benefit from having access to data from customer cars?

A.2 Transcript of interviews

In the section there will be a summary of each interview carried out for this study

A.2.1 Interview 1

Employer: OEM

Industry: Passenger cars

Position: Vehicle weight development

Duration: 35 minutes

- Input data for weight development:
    - Weight of components
    - Internal standard for passenger and luggage allocation (defining the weight and number of passengers as well as their assumed luggage)
- Output is used for:
    - Load requirements for certain systems (e.g. axles)
    - Calculation of centre of gravity (COG) → used for vehicles safety systems
- Possible use-cases for customer data in weight development:
    - Verification of current standard for passenger and luggage allocation
        - Based on readings from internal sensors the actual weight of a customer car can be approximated
        - A precise model can be developed how often which loading situation is present
        - More realistic axle loads etc. will help to develop vehicles more suitable for realistic customer usage
    - More detailed implementation of vehicle stability systems
        - The weight as well as centre of gravity are important input values for vehicle stability systems
        - COG changes with changing seat occupation and varying loading of the trunk
        - COG calculation is based on an internal standard for passenger and luggage allocation
        - Only one COG is used for the implementation of stability systems
        - With detailed customer data a better knowledge of loading situations could be gained

        - Different implementations for different loading scenarios could be implemented (load detection in the car necessary to switch to the most suitable implementation)

- Possible use-cases for customer data in other fields of development:
    - Extreme situations defining requirements
        - The dimensioning of many systems is primarily defined by certain extreme situations (e.g. hill decent with heavy trailer for brakes, axle articulation for driveshafts and air spring bellows,
        - Customer data could verify whether these conditions are present in real life
        - A small reduction of requirements from these dimensions-defining situations could reduce costs significantly
    - Predictive maintenance:
        - A large pool of customer data will be necessary to implement a fully functional predictive maintenance systems for customer vehicles
        - Through implementation of artificial intelligence, the system's prediction will become better over time
        - Customers will be able to have components repaired or replaced before their failure would damage of a more a costly vehicle part (e.g. replace oil pump before engine breaks down)
    - Guided maintenance
        - If vehicle sensors detect an extreme driving situation (e.g. deep pot hole), during the next inspection the mechanic will get an automatic request to check or replace certain parts
        - If vehicle detects a situation which is likely to cause a critical failure, the driver will be notified to have their vehicle serviced
    - Continuing development of autonomous driving systems
        - Experience with autonomous driving systems is still limited due to the novelty of the technology
        - Traditionally, data for development originates from vehicles tested by OEM employees
        - Usage of customer data will increase the data pool significantly and will help OEMs to gain more experience with real life scenarios in shorter time
        - Customers could profit from giving OEMs access to their vehicle's data by getting updates to their systems
    - More realistic test procedures
        - For most components there are internal test standards which define how often a certain situation will be experienced throughout a vehicle's service life (e.g. number of times a door is opened, or a button is pressed)

        - With an easy to implement counter and the already existing sensors or switches, a more precise approximation for the repetitions of operations could be realised
    - Seat development
        - Based on existing sensors in the seats and load data approximation a better understanding of seat occupation as well as passenger weight and size can be achieved
        - Better fitting seats for typical driver and passenger
        - Maybe different seats for different sales regions
    - Acoustic development
        - For the acoustic development the wind noise is a significant factor; the higher the expected speeds the more elaborate the measures to maintain the desired noise level
        - Certain measures for high-speed travel are only needed if the vehicles are actually driven at high speeds → potential to reduce weight and costs in low-speed markets
        - Actual driven speeds might differ from existing speed limits in the respective market
        - Data from customer cars could give an indication for the classification of high-speed and low-speed countries
    - Battery of electric cars
        - Load cycles and charging conditions define the service life of electric cars' batteries
        - There is limited knowledge about the number of loading cycles, the amount of charge during a loading cycle and the percentage of AC and DC charging
        - Using customer data, the knowledge base about the typical charging behaviour of customers can be extended and more realistic requirements can be defined
- Annotation regarding obligation to increase requirements if necessary:
    - With current requirements and test procedures OEMs define the state-of-the-art
    - If feedback though customer data show that certain requirements are not high enough, OEMs will be liable to adapt their requirements accordingly
    - Increase of requirements will most likely mean higher costs

A.2.2 Interview 2

Employer: OEM

Industry: Commercial vehicles

Position: Acoustic development

Duration: 40 minutes

Summary:

- Input data for acoustic development
    - Legal requirements
        - Drive-past noise
        - Standing noise
        - Noise of horn
        - Noise at brake pressure discharge
        - Night time requirements (special engine setting, door slamming, etc.)
        - Laws for work place environment
    - Customer requirements
        - Noise of door closing mechanism in a city bus (work place quality for the driver)
        - Overhead noise emission experienced in 1st floor apartments next to a bus stop
    - Internal standards
        - Stiffness of cabin and frame
        - Noise level inside cabin at different driving situations
        - Noise quality (loudness, sharpness, frequencies)
        - Brand-specific positioning
- Requirements for acoustic development are derived from:
    - Laws in all markets → strictest laws set the threshold for the entire vehicle
    - Competitor benchmarking
    - Customer clinics
    - Internal standards which are to some based on a subjective evaluation of the in-situ noises
- Possible use-cases for customer data in vehicle development:

- Durability:
    - certain customers complain about premature failure of axles or chassis parts
    - There is already a data logger for engine torque in current models which stores the torque history locally on an ECU
    - Torque data showed that customers overloaded their vehicle and that a failure of axles can be explained by this
    - Local inspections of the workflow showed high impact loads on the flat bed through dumping of heavy loads from significant heights
    - More detailed logging of data would make it possible to inform customers about an overloading and could assist the OEM in case of a law suit
    - Better knowledge of customer behaviour could be used for special "heavy duty" models or for a better customer communication regarding what usage is considered misuse
- Engine development:
    - Strain on engine components depends heavily on the power output used over life time
    - In the development of engines, a representing mix of high power output and low power output is used for qualification and verification
    - Data logging of customer vehicles could alter the current design guide lines towards a more realistic approach
    - Maybe a differentiation of requirements regarding regions would be feasible
- Infotainment:
    - Infotainment systems in commercial vehicles differ from systems used in passenger cars
    - In current navigation systems the driver searches for an address or a point of interest (POI)
    - In many cases, the driver's wish is not to go to a certain address but to satisfy a desire or wish (find the best café along the route, etc.).
    - Customer data could help to understand the wishes drivers have and could enable the implementation of a smart navigation system which will recommend places based on these desires
- Understanding of customer usage of certain functions:
    - The development of each function offered in a vehicle is very costly
    - Analysis of customer data could tell which functions are actually used and which are obsolete
- Function on demand (FoD):

    - When comparing traditional sales of options with selling function on demand purchases, the more profitable business case can depend on the particular function (when buying an option, the customer spends the money regardless of how often the function is used; FoD functions which do not give a benefit will not be booked again)
    - With knowledge of the actual usage of certain functions the OEM can evaluate whether sales of options or FoD will generate a higher income
  - Electric mobility:
    - Many customers worry about the usability of electric vehicles for a commercial use
    - With an extensive data base of real customer data potential customers could be convinced that for certain applications electric vehicles could make sense
    - Positioning of charging stations etc. could be optimized based on real life customer data
  - Routing and fleet management service
    - Customer data could enable OEMs to offer customers precise services regarding optimal routing of deliveries and choosing the best vehicle for each application (type of propulsion, vehicle size, …)

A.2.3 Interview 3

Employer: OEM

Industry: Commercial vehicles

Position: Diesel engine development

Duration: 70 minutes

Summary:

- Input data for diesel engine development
    - Emission laws
    - Performance requirements based on…
        - Comparison with competitor vehicles
        - Direct customer input (e.g. customer clinics)
    - Long-term durability requirements
        - Based on assumptions regarding the typical use by customers
        - Target values based on mileage over lifetime
    - Brand specific characteristics
        - E.g. requirements up to which altitude full power is available
        - Evolved over decades and are now part of the brand DNA
        - Assumption: customers want to feel these characteristics if they buy a vehicle of this specific brand
- Possible use-cases for customer data in diesel engine development:
    - There is already a basic logging of vehicle data on certain ECUs
        - No time data, just histograms of events
        - Data can only be accessed through vehicle's hardware connection
    - SCR catalytic converter
        - SCR catalytic converters degrade over lifetime
            - degradation is governed by temperature exposure
            - degradation increases exponentially with increasing temperature
        - Temperature in SCR system is dependent on:
            - ambient temperature
            - Power output (power output is typically restricted to protect SCR system)

    - SCR system includes several temperature sensors to monitor exhaust temperature
    - If temperature of customer vehicles could be analysed, engine power could be tweaked up without risking premature breakdown of SCR system
    - Different engine mappings for different sales regions could be developed
- Alternator in hybrid drive trains
    - The alternator in a hybrid drive train will experience a lot more use than in conventional engines
    - Not a lot of experience of how many starts are likely in typical customer usage
    - Analysis of data from customer vehicles would allow for a more accurate testing standard and higher confidence
- Cloud computing of injector drift
    - Diesel injectors might experience a drift regarding their flow rate
    - Injector drift is a stochastic phenomenon and cannot be predicted by the engine control software
    - Calculation of actual drift is costly in terms of computational power
    - Calculation of drift is necessary once a day or less
    - With transferring data from the vehicle to OEM servers, the computation could be done in the cloud and computational power in the vehicle can be reduced → reduced costs for ECUs
- Enhancement of engine models by increasing sample size
    - Simulation models (e.g. for engine pressure during combustion) are based on data from a few test-engines equipped with special sensors → limited sample size for developing the model
    - Sensors are expensive and have a limited life time → customer vehicles are not equipped with these sensors
    - A certain number of customer vehicles (between several hundreds to a few thousands) could be equipped with additional sensors → limited increase of costs
    - If sensors fail customers will not experience any change for the worse as sensors are not necessary for engine performance
    - Transferring sensor data over-the-air to the development centre would increase the sample size to build the engine model on dramatically
    - In comparison to operating a fleet of testing vehicles, the costs of additional sensors in customer vehicles is negligible

- Possible use-cases for customer data in other fields of development:
    - Enhance durability requirements:
        - The requirements for durability development are based on several assumptions regarding the typical use
        - Almost all parts would benefit from requirements with higher accuracy (engine, axles, suspension, body)
        - Vehicles are already equipped with many sensors which can supply most variables necessary for better assumptions
        - The weight of the vehicle is not measured by sensors but computed based on power output, inclination and driving performance

A.2.4 Interview 4

Employer: OEM

Industry: Passenger vehicles

Position: Fuel consumption and emissions

Duration: 40 minutes

Summary:

- Input data for work in CO2 emission and fuel efficiency:
    - Laws regarding fleet consumption in different markets
    - Binding test standards for determination of pollutants and CO2 emissions (e.g. NEFZ, WLTP)
    - Vehicle specific variables influencing fuel consumption (e.g. drag coefficient, weight, rolling friction, etc.)
- Output is used for:
    - Determination of CO2 emission for specific vehicles as well as for fleet vehicle fleet in various markets
- Possible use-cases for customer data in CO2 emissions:
    - Fleet consumption value:
        - Currently, the fleet consumption is calculated based on the paper value of all sold vehicles. This doesn't necessarily represent the real-life emissions (e.g. a sports car might have a high fuel consumption on paper but has probably a lower annual mileage than a typical commuter car)
        - With connected cars the real consumption for each vehicle could be evaluated to calculate a real-life fleet value
    - Gear ratio
        - Typically, the gear ratio is chosen to realize an even partitioning with uniform changes of revolutions between gear changes
        - Low engine speeds can reduce fuel consumption significantly
        - Based on the driving behaviour of real customers, a different gear ratio might be acceptable or even preferable
        - An *overdrive* could help to safe significant amounts of fuel
    - Adjusting vehicle standard options with direct impact on fuel consumption:
        - Certain components have a strong influence on fuel consumption (e.g. wheels and tyres)

        - Analysing customers' driving behaviour could give the development department a better indication, whether options which cost a lot of CO_2 are actually needed for typical customer use (maybe tyres with low rolling friction are ok for most customers)
        - Stock options could be adjusted to the needs of real customers rather than to wishes of R&D departments
- Possible use-cases for customer data in other fields of development:
    - Counter of function usage:
        - Based on customer data it could be analysed how often every button / function is used
        - Those button or functions which are rarely used by customers can be omitted in future cars
    - Ergonomics
        - In future cars touch displays will replace buttons and dials
        - Touch displays are more difficult to operate without eye contact
        - Number of operating errors (off target touch) could be analysed and used for better ergonomics
    - Menu structure in infotainment system
        - Certain functions can be accessed using different ways through sub-menus
        - Some functions are hidden deep into several layers of sub-menus
        - With an analysis of customer behaviour those functions used more often can be placed on a higher level
        - Redundant access ways to the same function can be omitted if not used by customers
    - Implementation of customer-feedback system
        - With connected cars, a direct link between customers and OEM could be included within the vehicle's infotainment system
        - Customers could give feedback about experienced problems with their car or suggestions for improvements
        - Through a direct interaction with OEM customers would feel taken seriously and would be more willing to share their data
    - Optimized climate control
        - Despite having automatic climate control in most cars, customers tend to manually adjust the operation if it's very hot or cold
        - However, due to closed vents etc. the intended result (e.g. quick cool down of the interior) might be impeded

        - Analysing the usage of the climate control, R&D can understand the intention of customers and develop control strategies aiming at the specific customer intentions (e.g. offering “quick cool down” in the control menu)
    - Customer-oriented development: windscreen washer fluid
        - Customers have to regularly replace certain fluids such as windscreen washer fluid
        - The size of the fluid container in the car is based on the available space as well as internal standards
        - Based on customer data, it can be analysed how often customers in real life have to refill → tanks size could be adjusted
    - Classification of countries regarding their climate & road conditions:
        - Depending on the sales region, vehicles are fitted with special parts: larger radiators in countries with hot climate, bash plates in countries with bad roads etc.
        - In certain markets options such as large wheels or sport suspension are not offered because of bad road conditions
        - The country classification is usually done based on singular inspections
        - Based on the reading from temperature sensors in customer cars a more customer relevant classification of countries regarding their temperature exposure (super-hot, hot, normal, cold) could be established
        - Based on readings from temperature sensor and rain sensor a precise approximation of corrosion relevant conditions in different countries could be established
        - Based on readings from wheel travel sensors and accelerations a more precise classification of countries with bad roads could be established
- Annotation regarding adjustment of requirements:
    - OEMs will be very careful reducing their requirements
    - If anything happens due to reduced requirements it will be difficult to explain for OEMs why lowered standards seemed safe

A.2.5 Interview 5

Employer: OEM

Industry: Sportscars & Motorsport

Position: Chassis design

Duration: 30 minutes

Summary:

- Input data for chassis design in motor sport:
    - Regulation of relevant motorsport series
    - Chassis geometry of base vehicle
    - Load data measurement on most relevant race track
- Possible use-cases for customer data in motor sport:
    - Difference between company-own race team and customer teams
    - Company internal team:
        - All safety relevant parts have load sensors applied
        - Parts are exchanged depending on the real loading history → very high safety standard
    - Customer teams:
        - No load data analytics for each part is done (too expensive, too complicated)
        - Based on load data from reference tracks, a fixed interval for part exchange is defined
        - When looking at total costs of ownership the costs for exchange pf parts are at least on the same level as the purchase price of the race car
        - With smart algorithms data from existing sensors could be used to approximate the loads of critical or expensive parts
        - Exchange of parts could be done according to their actual load history → significant cost reduction for racing teams
- Possible use-cases for customer data in sport cars:
    - Compared to on-road usage, driving on a race track leads to significantly higher loads on almost all vehicle parts (engine, brakes, chassis, shocks, etc.)
    - The percentage of usage on a race track is not known
    - A survey among customers showed that with increasing purchasing price the amount of mileage on a racetrack increases

- With a racetrack recognition algorithm (e.g. based on GPS, accelerations, etc.) could help the OEM to define feasible assumptions regarding track usage for each vehicle type
- There is one OEM that will soon introduce customer data analysis with a racetrack recognition algorithm as a first use-case; durability department will have the lead in development of this use-case

A.2.6 Interview 6

Employer: OEM

Industry: Passenger vehicles

Position: Durability

Duration: 50 minutes

Summary:

- Input data for durability development
    - Vehicle requirements (a certain mileage on specific test tracks or road segments
    - Company requirements about the statistical design philosophy (confidence interval, tolerable failure rate, etc.)
    - Load data from vehicle measurement
    - Test requirements for misuse and abuse conditions
- Possible use-cases for customer data in durability development:
    - Re-design of design requirements in regard to relevant test tracks:
        - The current requirements have been developed for normal passenger cars
        - Heavy SUVs with larger suspension travel and larger wheels don’t exhibit relevant loads on those tracks relevant for passenger cars
        - SUVs exhibit high loads in driving conditions which are uncritical for passenger cars
        - A re-adjustment of test requirements in regard to relevant test tracks should be executed
        - Customer data could be used to analyse what kind of road conditions a SUV experiences over lifetime → with this data relevant tracks could be established
    - Do the anticipated misuse and abuse conditions take place in real life?
        - Misuse conditions rather than fatigue loads are the decisive factor for chassis design → even a small reduction of some test conditions could reduce weight and costs significantly
        - With feasible algorithms misuse conditions could be identified using the existing sensors
        - Based on customer data it could be analysed which misuse conditions actually take place and whether drivers bring their car for inspection afterwards

  - Misuse detection algorithm
    - Based on data from a large number of customer vehicles a reliable algorithm for misuse / abuse detection could be implemented
    - Misuse detection could be used to actively warn drivers about likely damages
    - With connected cars, an appointment with a service station could be organized and the mechanic could receive a warning regarding potential damages in certain components
    - With a reliable detection “hidden” damages could be acceptable
  - Torque prediction
    - Not all engine and gearbox combinations are tested regarding the torque loads on drive shafts
    - Internally, an interpolation model is used to forecast the torques on drive shafts
    - Customer data could be used to verify or adjust these models
- Possible use-cases for customer data in other fields of development:
  - Reduce overengineered solutions:
    - In most designs a maximum of requirements is to be fulfilled
    - With access to customer data these requirements could be adjusted to the real world
    - It is likely that requirements could be reduced and thus costs and weight could drop
  - Question special-use scenarios which govern construction of certain components (e.g. trailer use in steep downhill)
    - Customer data could be used to check whether these conditions take place in real life
  - Customer usage detection:
    - How often do customers use which function/button?
    - Functions with hardly any usage can be neglected in future vehicles → lower costs in R&D as well as in production and logistics
  - Better accuracy with forecasting customer wishes
    - Certain vehicle characteristics are defined based on sales figures of previous models or the subjective assessment of high ranked managers
    - When analysing customer usage rather than sales numbers, OEMs could gain a better understanding of customers’ real wants
    - e.g. if the majority selects the comfort mode in their automatic suspensions it is likely that customers thrive for more comfortable suspensions than those offered as stock

- Competition of features
    - Real customers could be used as a test group for new features
    - Giving one group of customers a different implementation of a certain feature than the other group, a direct comparison of usage would lead to a clear answer of how the best implementation should look like
    - If only a limited number of features could be offered, comparison of usage in different user groups could tell OEMs which has the biggest additional value to customers

A.2.7 Interview 7

Employer: OEM

Industry: Passenger vehicles

Position: Data Analyst in Durability Department

Duration: 60 minutes

Summary:

- Data size:
    - Tesla collects up to 3GB of data per day and vehicle
    - Full trace of all sensors in time domain would exceed manageable amount of data
    - Weighing up between large data being transferred to the servers and analysed in the cloud vs. data handling within the car and transferring of the results
    - Real-time monitoring and decision making (= preselection) on which data are noteworthy within the vehicle → only these data will be transferred to servers
    - Pre-selection based on pre-defined models, which are developed using data from development vehicles (supervised learning)
    - Pre-selection algorithms can vary from simple analytical models (sensor value higher than a threshold value) to models with complex evaluation of various input variables
    - Self-learning algorithms not feasible to use in customer cars as they need too much computing power which is better used for autonomous driving capabilities etc.
- Data collection models:
    - Event counter
        - Will increase the current counter value every time the pre-selection model is triggered
        - Result is a number
        - No increase of data size (only the counter is increased)
        - Example: how often is s certain button used?
    - Data classification
        - Will increase the corresponding counter for a certain situation (multi-level counter) defined by the pre-selection model
        - Result is a histogram
        - No increase of data size (only the values increase)

        - Example: How often is how much torque delivered?
    - Selected time frame
        - Time data of pre-selected sensors are collected for a certain time frame if the pre-selection model triggered
        - Data points before and after the trigger can be collected
        - Choice of sensors (number and type) crucial for data size
        - Size of data increase with number of vehicles and time
        - Example: Video data from outside facing cameras in the event of autonomous driving functions detect irregularities
    - Full trace
        - Size of data increase with number of vehicles and time
        - Due to data amount not very practical in customer fleet
        - Example: telemetry in motorsport
- Different implementation techniques
    - Static implementation:
        - Model for preselection is implemented statically on an ECU in the car
        - Fixed selection of sensors
        - Preselection model or type of data which is collected cannot be changed once the vehicle is sold
        - Typically used for counting or scoring algorithms which give histograms as a result
        - Back-end for data collection on OEM servers is programmed once. No changes or adaptations necessary
    - Successive Campaigns:
        - The ECU assigned for data collection can be re-programmed over-the-air
        - Different data collection campaigns with varying choice of sensor data and pre-selection models are implemented on the same vehicle one after another for a limited time
        - Flexible and adaptive decision on data collection program based on current needs in the development
        - Limited capability of hardware for measuring various channels
        - More efficient use of data
            - once a certain amount of data points is analysed, there is no additional gain by collecting even more data points
            - Several data collection campaigns with different scopes give OEMs better insight than the same collection of data for several years

    - When campaign is changed ECU within the car and back-end server have to be re-programmed

- Data Analysis and Back-End handling
    - Back-end must be tailored to implementation of data collection in the vehicle
    - To make full use of huge amount of data artificial intelligence algorithms are necessary → analytical models for data interpretation are expected to be of only limited use
    - Restricted access to time domain data due to privacy considerations (local copies of vehicle data are critical) → if possible only processed data (results) are given to developers
- Artificial Intelligence (AI) as enabler for big data handling
    - AI can help in two phases of the data collection
        - Models for data pre-selection are derived from data collected from development fleet using AI
        - Analysis of customer data needs to be done with AI as soon as complex data is looked at
- Possible use-cases within durability department:
    - Classification of countries regarding temperature, road quality, etc
        - Histogram of temperature, accelerations, etc.
        - Better understanding of regional requirements → which additional measures or restrictions are necessary?
    - Classification of road types
        - How high is the percentage of use on motorways, country roads and city roads?
    - Typical loading situation
        - How often is a vehicle used fully loaded, with only one passenger, etc?
    - Occurrence of misuse situations
        - Do the anticipated misuse scenarios take place in real life?
        - How often do high load situations take place over life time?
    - Engine use
        - How often is full power output used?
        - How often is full torque delivered?
        - How many starts of the alternator?
        - Do customers respect warming-up phase?
    - Classification of steering
        - How often is full steering angle used?
- Possible use-cases in other fields of development
    - Reduction of number of sensors:

        - Using AI techniques, maybe there is a possibility to forecast the reading of a certain sensors by the results of other sensors
        - Replacing one sensor can safe save money in every car built
        - Based on data from customer cars, the model to replace the sensor can be verified
    - Customer usage of certain functions
        - Do customers use certain functions or buttons?
        - Replace buttons which are not used by those of functions used more often
    - Forecast customer wishes:
        - Try to forecast customer wishes for the base model based on their use of options
        - Example: if customers with adjustable suspension use comfort mode most of the time there is need for a more comfortable base setting
    - Usage score
        - Implementation of a scoring system which evaluates the driver's behaviour regarding the vehicle's long-term quality
            - How often high revs when engine was cold?
            - How much driving with high payload?
            - How many misuse situations?
        - Usage score could be a quality attribute when selling the car similar to service history etc.

A.2.8 Interview 8

Employer: OEM

Industry: Passenger vehicles

Position: Project management full vehicle development

Duration: 45 minutes

Summary:

- Possible use-cases for customer data in vehicle development:
  - Ergonomics of user interface:
    - What are the typical user settings? → Adjustment of default settings in the future
    - How long does it take for customers to get used to the system? (What are typical mistakes etc)
    - How high is the distraction of certain apps or menus? (evaluation of vehicle control or steering corrections)
    - Which features are used in which traffic situation? (motorway, stop-and-go, …)
  - Increase of autonomous driving capabilities:
    - Replace large and costly development fleet operated by OEM partly by data from customer cars
    - Use customer data in two phases of development:
      1. Learning of situations and scenarios:
         - Customer data is used as input for models
         - Data is selected depending on certain traffic situations or weather conditions
      - Testing of developed models:
        - Large amount of testing could be done on simulators rather than in real cars
        - Customer data could be used as input data for simulators
        - Accelerated testing in various markets and in selected critical situations
  - Battery usage in electric cars
    - Not much experience with electric cars yet
    - Using customer data is cheaper and faster than using only data from test vehicle fleets
    - Customer data could get a better understanding of:

        - Temperature conditions of life time and resulting ageing of the battery cells
        - Are there limiting factors due to the climatic conditions in certain markets?
        - What is the typical distance driven between charging?
        - How many charging cycles with which power over life time?
        - Is high power-output used?
        - Percentage of short / medium / long distance travel
        - Data could be used to communicate to potential customers that electric range will be sufficient in most use-cases
- Positioning of charging port of electric vehicles
    - In contrast to vehicles with combustion engine there is no standard location for the charging port of an electric vehicle
    - In current models the charging ports location vary between the front grill, front fenders, C-pillars and rear lights
    - Based on data of vehicle cameras and parking sensors it could be established how much customers have to walk around the car before they can plug in
    - Potentially, the preferred location may vary in different markets due to different customer habits
- Power of climate control
    - If a large percentage of customers use the air conditioning or the heated seats on full power it is likely that they would use an even higher setting if available
    - Readjustment of requirements for next generation of cars
- Classification of regions
    - Different regions are clustered according to temperature, road conditions, fuel quality and altitude requirements
    - Today, this classification is based on sporadic field trips
    - Based on customer data the regional classification could be done more precise
    - Due to limitation of range options and requirements for additional parts (sump guards, larger radiators etc.) costs could be reduced and revenues increased
- More realistic requirements of components
    - For the developments of each component, OEMs assume a certain usage behaviour
    - With the use of customer data OEMs could derive more accurate requirements for their development (e.g. wiper motor)
- Do customers use what is offered to them?

    - Are features actually used?
    - If functions are not used, in the next generation of cars costs for development and costs for the respective parts could be saved
  - Trend scouting
    - Early understanding of future trends will give an advantage in the timely development of certain functions
    - New trends could be forecasted based on the data from customer cars
      - Which Apps are used on mobile phones connected to the vehicle?
      - What do users search for when using the internet connection of the vehicle?

A.2.9 Interview 9

Employer: OEM

Industry: Passenger vehicles

Position: Technical procurement

Duration: 25 minutes

Summary:

- Engine testing
    - Engine testing is done on test benches according to pre-defined test procedures
    - Testing with data from real customers would give a better understanding of what is important to customers (fast acceleration, high torques, etc.)
- Connected services
    - The amount of data transferred through mobile data connection of vehicles is just assumed; there are no records of real use available
    - It’s likely that data usage differs significantly depending on the region
    - Analysis of customer usage would give OEMs the ability to estimate the required bandwidth and data volume for each market or region
- Function on demand (FoD)
    - Offering customers additional services for a limited time (e.g. additional battery capacity or heated seats)
    - Better understanding of the business case:
        - Which options are feasible for FoD?
        - Which options generate higher profits when offered as FoD or as classic option sales
    - Pre-active offering of FoD options according to certain situations
        - E.g. connected vehicle detects an upcoming holiday trip through emails on the phone which is connected to the car. The car will offer a FoD-package with adaptive cruise control etc. for the time of the planned trip
- After Sales Offers:
    - Customers with a certain driving behaviour get certain after sales offers
    - E.g. drivers with sporty driving style are offered an increase of limited top speed
- Evaluation of warranty claims

- OEMs can check whether the driver did any changes to the vehicle which might compromise the warranty
- Misuse situations etc. are logged
- Risk: customer will feel monitored by the system rather than supported