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Connected Car API - Platforms

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Zusammenfassung

Die zunehmende Vernetzung von Fahrzeugen ist zu einem wichtigen Instrument der Automobilhersteller geworden, um Sicherheit und Komfort zu erhöhen. Um den Zugriff auf die Daten eines vernetzten Fahrzeugs auch für Dritte zu ermöglichen, haben die Hersteller damit begonnen offene Programmierschnittstellen (APIs) zu entwickeln. Diese ermöglichen es Serviceanbietern Fahrzeugdaten und Fahrzeugfunktionen für die Entwicklung von zusätzlichen Diensten rund um das Fahrzeug zu nutzen. Hierfür gibt es bereits Anbieter von vernetzten Fahrzeugschnittstellen (engl. Connected Car APIs), die mit ihren standardisierten Schnittstellen verschiedene Hersteller universell ansteuern können. Die vorliegende Arbeit thematisiert die grundlegende Funktionsweise eines vernetzten Fahrzeugs, die Bedeutung & Relevanz von Fahrzeugdaten und wie sich die Plattformen einzelner Anbieter von Connected Car APIs in ihrem Geschäftsmodell, ihrer Funktionalität und der Anwenderfreundlichkeit unterscheiden. Dabei werden folgende Forschungsfragen gestellt: *Sind herstellerübergreifende Fahrzeugschnittstellen praxistauglich und bieten diese Vorteile im Vergleich zu herstellereigenen Plattformen? In welchen Anwendungsfällen sind herstellerübergreifende und wann herstellereigene Lösungen besser geeignet?* Um diese Forschungsfragen zu beantworten, wurden Connected Car API-Plattformen prototypisch implementiert und evaluiert. Zudem wurden die Plattformen anhand von Literaturrecherchen analysiert und Experten aus der Praxis in Bezug auf Fahrzeugschnittstellen befragt. Anhand von fachlichen und technischen Kriterien werden herstellerübergreifende Plattformen ("High Mobility", "Otonomo“ & „Smartcar“) einer proprietären Alternative der Daimler AG gegenübergestellt. Es zeigt sich, dass die Kontrolle der Fahrzeuge und deren Daten von den Herstellern vordefiniert sind und sich die Plattformen untereinander in ihrem Datenangebot kaum unterscheiden, da sie auf die regulären Datenprodukte der Herstellerplattformen zugreifen. Dennoch positionieren sich diese Plattformen unterschiedlich auf dem Markt und bieten den Vorteil, dass eine datenschutzkonforme Anbindung sowie die Fahrzeugkommunikation nur einmalig implementiert werden muss und diese ohne individuelle vertragliche Verhandlungen herstellerübergreifend genutzt werden kann. Herstellereigene Plattformen haben den Vorteil, dass sie auf Kundenanforderungen schneller reagieren können, da die Daten direkt vom Hersteller bezogen werden und zudem auch Datenprodukte zur Verfügung stehen, die noch nicht öffentlich erhältlich sind. Eine gesetzlich vorgeschriebene Bereitstellung von Daten gibt es noch nicht, da viele Hersteller dazu technisch noch nicht in der Lage sind. In ihrer technischen Implementierung unterscheiden sich die Plattformen nur im Detail, wobei es durchaus Unterschiede in der Entwicklerunterstützung gibt. Es ist empfehlenswert herstellerübergreifende Schnittstellen für das Abrufen von kumulierten Daten sowie für Anwendungsfälle zu nutzen, die für mehrere Hersteller gedacht sind. Bei homogenen Flotten oder spezifischen Fahrzeuganforderungen ist eine Herstellerplattform eine sinnvolle Alternative. Sowohl proprietäre als auch herstellerübergreifende Connected Car API Plattformen haben ihre Vorteile und werden in Zukunft ihr Datenangebot weiter ausbauen. Beide sind in der Praxis anwendbar sofern der derzeit noch begrenzte Umfang an Daten den Anwendungsfall nicht einschränkt.

Schlagworte: Connected Car, Connected Vehicle, API-Plattform, vernetztes Fahrzeug, Fahrzeugdaten

Abstract

The increasing connectivity of vehicles has become an important instrument for car manufacturers to improve safety and comfort. To enable third-parties to access the data of a connected vehicle, the manufacturers have begun to develop open application programming interfaces (APIs). These enable service providers to use vehicle data and vehicle functions for the development of additional services related to the vehicle. For this purpose, there are already providers of connected car APIs existing that can address various manufacturers universally via standardized interfaces. This thesis describes the basic functionality of a connected vehicle, the importance & relevance of vehicle data, and how the platforms of individual providers of connected car APIs differ in their business model, functionality, and usability. The following research questions are discussed: *Are cross-manufacturer vehicle interfaces feasible and do they offer advantages compared to proprietary platforms? In which use-cases are cross-manufacturer and when are proprietary solutions more appropriate?* To answer these research questions, connected car API platforms were prototypically applied and evaluated. Besides that, the platforms were analyzed based on literature research and interviews with experts from the professional field of vehicle interfaces. On the basis of a business and technical criteria, the providers of cross-manufacturer platforms ("High Mobility", "Otonomo" & "Smartcar"), and a proprietary alternative from Daimler AG were compared. It turns out that the data and vehicle control are pre-defined by the manufacturers and that the platforms hardly differ from each other in their data offered, as they all access the same data products of the manufacturer platforms. Nevertheless, the cross-manufacturer platforms appear differently on the market and offer the advantage that a data protection-compliant connection and vehicle communication only has to be implemented once and can be used across manufacturers without individual contractual negotiations. Proprietary platforms have the advantage of being able to react faster to customer requirements since the data is obtained directly from the manufacturer. Moreover, data products may be accessible that are not yet publicly available. There is no legal obligation to provide data, as many manufacturers are technically not able to do so yet. In their technical implementation, the platforms only differ in detail, although there are certainly differences in developer support. It is recommended to use cross-manufacturer platforms for retrieving aggregated data as well as for use-cases that are intended for multiple manufacturers. For homogeneous fleets or specific vehicle requirements, a manufacturer platform is a reasonable alternative. Both proprietary and cross-manufacturer connected car API platforms have their advantages and will further expand their range of data offered in the future. Both are applicable in practice, if the current, still limited scope of data does not restrict the use-case.

Keywords: Connected car, Connected vehicle, API platform, Vehicle data

Contents

List of Abbreviations

3G	3rd generation of wireless mobile telecommunications
4G	4th generation of wireless mobile telecommunications (LTE)
5G	5th generation of wireless mobile telecommunications
ACEA	European Automobile Manufacturers Association
AI	artificial intelligence
API	application programming interface
ADAS	Advanced Driver Assistance Systems
AWS	Amazon Web Services
B2B	Business-to-Business
B2M	Business-to-Municipalities
BYOCAR	Bring-Your-Own-Car
CAN	Controller Access Networks
Car2X	car-to-everything
CCC	Car Connectivity Consortium
CCPA	California Consumer Privacy Act
CVIM	common vehicle information model
CoO	country of operation
CSV	comma-separated values
eCall	emergency call
ECU	Electronic Control Unit
EEA	European Economic Area
eSIM	embedded SIM card
EU	European Union
EV	electric vehicle
ExVe	Extended Vehicle
FCA	Fiat Chrysler Automobiles
GDPR	General Data Protection Regulation
HMI	human-machine interface

IANA	Internet Assigned Numbers Authority
IETF	Internet Engineering Task Force
IoT	Internet of Things
ISO	International Organization for Standardization
JLR	Jaguar Land Rover
KTM	Kronreif Trunkenpolz Mattighofen
LBS	location based services
GM	General Motors
GMC	General Motors Company
GPS	global positioning system
HTTP	hypertext transfer protocol
MB	Mercedes-Benz
MBUX	Mercedes-Benz User Experience
MCVP	Microsoft Connected Vehicle Platform
MMC	Mitsubishi Motors Corporation
npm	Node Package Manager
OAuth	Open Authorization
OBD	on-board diagnostics
OEM	original equipment manufacturer
OTA	over-the-air
OTT	Termed-Over-The-Top
PAYD	Pay-As-You-Drive
PSA	Peugeot Société Anonyme
RDS	Remote Diagnostic Support
REST	representational state transfer
RMS	Remote Maintenance Support
RSI	Restful Service Interface
RTTI	real-time traffic information
SAE	Society of Automotive Engineers
SDK	software development kit
URI	unique resource identifier
URL	unique resource locator
VIAS	Vehicle Information API Specification
VIN	vehicle identification number

VISS Specification for the Vehicle Information Service

VSS vehicle signal specification

VW Volkswagen

W3C World Wide Web Consortium

WLAN Wireless Local Area Network

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1 Introduction

Vehicles become more and more a source of valuable information for in-vehicle, cross-vehicle, and cloud-based applications that improve performance, safety, efficiency, and entertainment. They can also be part of an entire ecosystem to address issues of general convenience and safety, to network transport systems and other infrastructures with car-to-everything (Car2X) interactions into a smart city.

The basis for the data exchange of a vehicle is the equipment of a telematics unit, which provides access to the internet and therefore enables connectivity. In conjunction with programming interfaces and corresponding data models, this enables data exchange with the vehicle. To enable third parties to access the data of a connected vehicle, the manufacturers have begun to develop and offer APIs as data products on proprietary connected car API platforms. These enable service providers to utilize vehicle data for the development of additional services around the vehicle. Driven by the international pressure to open up data sovereignty, manufacturers have committed providing access to their vehicles for third parties via so-called neutral servers independently and without any restrictions. The development of international standards enables cross-manufacturer data exchange between vehicle, original equipment manufacturer (OEM), and third-party application providers. For this purpose, providers of connected car-API platforms have emerged, which are capable to address vehicles in a universal and manufacturer-independent way with standardized interfaces.

1.1 Objective

This thesis is intended to provide a technical and business differentiation of pre-selected cross-manufacturer connected car API platforms and a proprietary manufacturer platform in comparison. Thereby the focus is on publicly accessible platforms that offer a development environment that is open to everyone without further approval. Based on self-defined business and technical criteria, suppliers of cross-manufacturer platforms ("High Mobility", "Otonomo" & "Smartcar") will be compared to a proprietary alternative of Daimler AG. The platforms will be analyzed in their business model, functionality, and usability from a third-party implementation point of view. The technical analysis will be based on a prototypical implementation to evaluate the convenience and design of the individual APIs. The results will be used to answer the following questions:

- *How do the platforms differ in their business model, functionality, and usability?*
- *Is the use of a cross-manufacturer connected car APIs platform feasible?*
- *Are there use-cases where cross-manufacturer platforms are better suited compared to proprietary platforms?*

In addition, information will be provided on the fundamental aspects relating to vehicle data interfaces, their standardization, data protection, and the relevance of the utilization of vehicle data concerning connected vehicles as well as the willingness of vehicle owners to share data.

1.2 Structure

The presented paper is divided into four chapters, opening excluded. The first part (Chapter 2) gives an overview of the differentiation of vehicle data and how this data is made available via telematics systems. In addition, an insight is given to the potential usage of vehicle data concerning connected car services in general. Additionally, the willingness of car owners to share vehicle data will be addressed. Furthermore, this chapter presents specifications for privacy and data protection as well as global initiatives and commitments for standardization of vehicle data communication. In the second part (Chapter 3), the examined connected vehicle APIs platforms will be introduced, including the real-life availability of vehicle data, their general principle of operation, and the differentiation from other connected vehicle platforms. Chapter 4 focuses on the individual platforms in detail and is divided into a business part (4.1), a technical part (4.2), and an overall comparison (4.3). In 4.1, the examined platforms will be described in detail with their features, pricing, and specialties, while in 4.2, the technical implementation is demonstrated from a third party perspective. Also, the technical evaluation of the APIs is included. The overall result is presented in (4.3), where the business and technical criteria as well as their evaluation are presented in a tabular form. Moreover, further considerations concerning the position of manufacturers, cost bearing, and potential risks are addressed in 4.4. The final part in Chapter 5 summarizes all results and gives a conclusion and outlook.

2 Connected car basics

This chapter builds the foundation regarding the understanding of a connected car, what vehicle-generated data is, how it is made available to automotive manufacturers and third-party companies, and what relevance this has for the future of vehicles.

The base concept of a connected car has its origin in the approach of connecting any digital device such as thermostats, lamps, and fridges to a network, so-called Internet of Things (IoT)[1].

The internal networking of a car connects Electronic Control Units (ECUs) and Controller Access Networks (CANs) together in real-time to control the car's systems, from window switches or climate control to Advanced Driver Assistance Systems (ADAS)[2]. Bringing this information to an external network via the internet is the next step in the digital transformation of a device, such as an automobile. In fact, connected vehicles are only one part in an ecosystem of IoT devices[3].

Overall, the definition of a connected car refers to any type of vehicle which is equipped with internet access via mobile communication networks to share vehicle information & vehicle-generated data and enable remote control. The capability of an internet connection is a fundamental foundation of any IoT device. In the case of a vehicle, this is meant to communicate with other vehicles & infrastructures (Car2X)[4] or to process vehicle data in real-time such as location or car health-related sensor information[2].

2.1 Connected car data

Based on the internal network of any vehicle with more than 100 sensors, an OEM is able to collect vehicle data from various potential sources that measure location, vehicle performance, and driving behavior, usually several times per second[5]. An overview is shown in the figure 2.1.

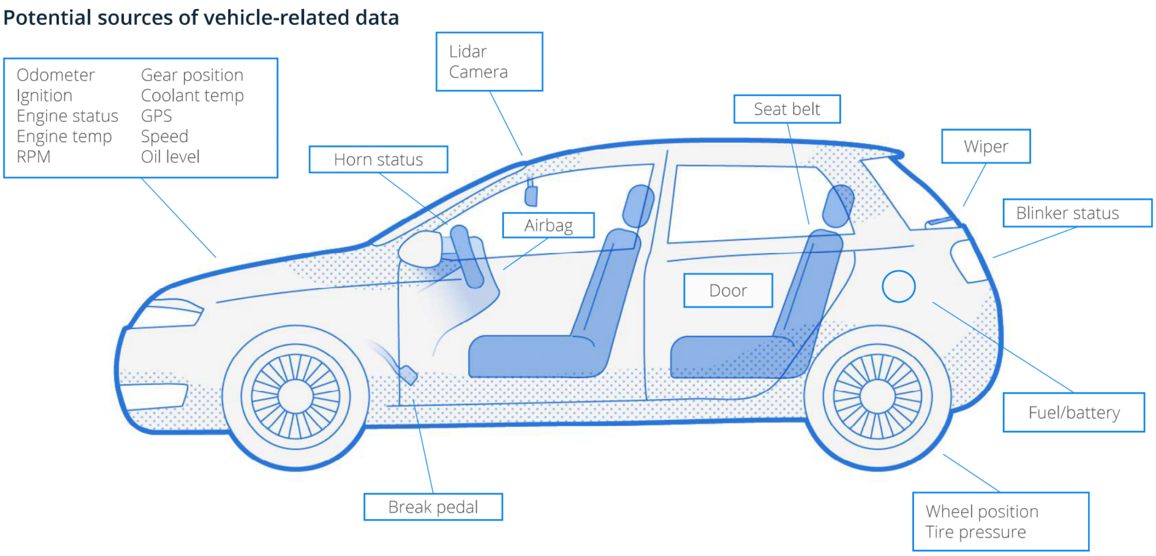

Figure 2.1: Potential sources of vehicle related data, Source: [6, p. 54]

The estimated amount of data generated in and by a vehicle is up to 25 gigabytes of data per hour which is equivalent to almost the amount of 30 hours of high-definition video streaming and more than the total of a month of 24 hour music listening, daily[5]. A comparison is shown in the figure 2.2.

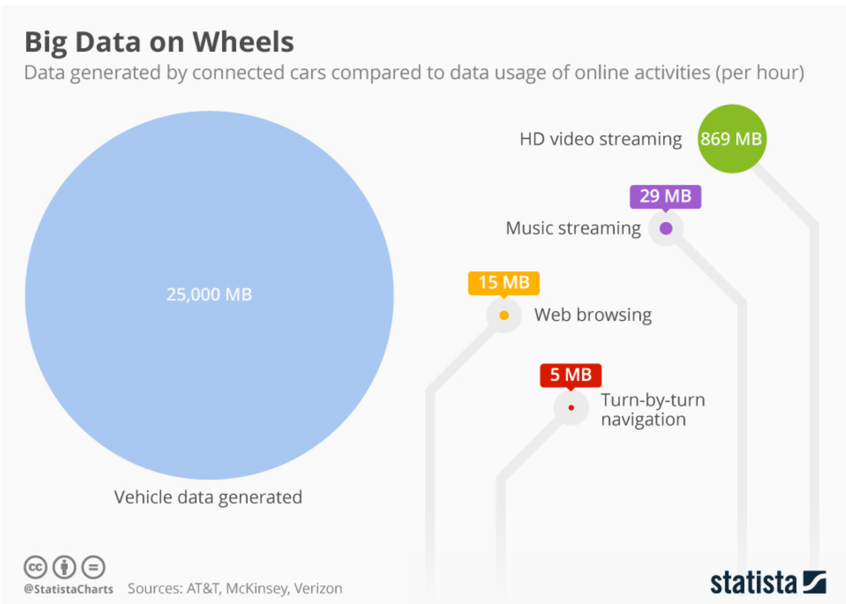

Figure 2.2: Estimated generated of a connected cars per hour, Source: [5]

2.1.1 Distinction between personal & aggregated data

In general, this vehicle-related data can be divided into two types of data: personal and aggregated data. Depending on the platform, aggregated data provides access to anonymized historical traffic, vehicle status information, or road-sign data related to the vehicle's conditions and working parts, whereas personal data is related to individual personal vehicles that are identifiable and corresponding to a certain vehicle identification number (VIN)[7, 8, 9]. Nowadays, this is typically used by retailers or workshops to read static specifics of a car, such as engine or fuel type information[6, p. 55]. Apart from this, the potential applications are services such as on-demand fueling/car wash, road assistance, car-rental/sharing, or in-car parcel delivery service[10]. Aggregate data is operating data which is provided in real-time related to the vehicle's conditions and working parts and contains all kinds of information which are influenced by the driver or passengers such as the current fuel level or brake pedal position. Moreover, the data is not limited to the information generated by the vehicle itself, surrounding values around the vehicle such as weather conditions can also be valuable.

However, the data communication does not only taking place in one single direction. Write access to a vehicle also enables remote control, such as door lock and unlock. How this vehicle data is protected to the OEMs and third-parties is described in the following section.

2.1.2 Privacy & data protection for vehicle data

Regarding the protection of personal vehicle data, which need to be considered, the regulations & principles of Europe and the USA are described in the following. Worldwide there may be different regulations for each region, each depending on the local laws.

General Data Protection Regulation

The most recent European-based mandate, the General Data Protection Regulation (GDPR)[11] came into force in May 2018 and is generally concentrated on the protection of personal data of citizens within the EU[12]. The GDPR is about personal data which is personal information that defines any kind of information related to an identifiable person.

The introduction of the GDPR implied new requirements for the treatment of personal vehicle data in the following terms: data consent, data collection, data processing, data access and request for deletion of data. In addition, it specifies the mandatory reporting of data breaches within 72 hours of discovery, rules to be defined on possible privacy violations, and the election of a data protection officer within a company. Privacy violations can cause a retribution of up to 20 million euros or four percent of the company's annual worldwide turnover.

Due to the increased installation of telematics systems into vehicles and the application of connected car features, more and more data is collected, used, and exchanged about the car. Applied to a connected vehicle, GDPR determines that no data should be transmitted to the manufacturer or third-parties unless the vehicle owner agrees to a valid contract with the manufacturer's connectivity service provider. However, the vehicle owner has no control over how and which data is processed or marketed by the OEM. If individual personal data, such as driving patterns, speed, acceleration, or vehicle stability caused by the user's behavior is to be requested from a third-party provider, the owner has the right to give his explicit consent separately[13].

The GDPR does not address data ownership, but rather data control[12]. OEMs have a special obligation in this respect, as they are the controlling entity for the release of data to third-parties and are therefore subject to increased obligations. Thus, it is their responsibility to implement appropriate security mechanisms to protect the data & privacy by design.

Automotive Consumer Privacy Protection Principles

In the USA the Alliance of Automobile Manufacturers formed consumer privacy protection principles already back in 2014, which have been updated in 2018[14]. Compared to GDPR these privacy principles for vehicle technologies and services are not obligatory and covers only roughly described principles.

However, with the California Consumer Privacy Act (CCPA)[15] the Federal State of California/USA, for example, has its own law which secures the personal rights of the inhabitants of California.

How the data communication with the car takes place is described in section 2.2.

2.2 Connected car data interfaces

In order to provide data communication between the vehicles and the OEMs in the first place, an off-board or on-board data access is necessary. The differences and their advantages and disadvantages are described hereafter.

2.2.1 Distinction between off-board & on-board data access

On-board data access means the access to data from the inside of a vehicle through a physical connection provided by the on-board diagnostics (OBD) interface[16]. However, this includes security risks as the vehicle data can be retrieved and manipulated directly inside the vehicle to influence its operation. Each new accessible data point of this interface increases the potential entry points for hacker attacks straight into the vehicle.

The off-board access for vehicle data access, on the other hand, allows OEMs the secure communication of vehicle data by means of an external server that can be accessed by third-parties. This provides an open but secure interface for third-party-access to the data, as this access is regulated by defined rules on data protection, competition, and technical specifications.

However, a stable mobile data connection is necessary for making all of this possible, which can be established in various ways. The following section describes the primary distinction between realizations of off-board & on-board connection. Furthermore, there are also so-called tethered and hybrid solutions using a smartphone as an interface to the internet[6, pp. 26], which this paper does not focus on.

2.2.2 Embedded telematics

The common way of connecting vehicles to the internet is done via embedded telematics which provides off-board data access and is based on information & telecommunication technology[6, p. 83][17, p. 7]. These systems are able to collect, analyze, send, and receive all kinds of vehicle-related data. A permanently built-in embedded SIM card (eSIM) provides constant internet connection with a mobile communication provider. OEMs equip their vehicles with this technology to enable mutual communication with other vehicles and devices.

Embedded telematics enables the capability of over-the-air (OTA) updates, comfort features like remote control or safety & security features such as automatic emergency calls. Since 2018, every newly registered vehicle in the European Union (EU) has to be equipped with embedded telematics, which is due to the introduction of the European emergency call (eCall) mandate[6, p. 51][18]. Since the installation of embedded telematics in vehicles is mainly driven by legislation, connected car features via telematics are rather no longer primarily offered by vehicles of premium car brands such as Audi, BMW, or Mercedes-Benz.

Evolution of embedded telematics

The first connected vehicles have been developed by General Motors (GM) in 1996[19]. With this first car-embedded telematics system the American car manufacturer made it possible for customers to establish in-car voice calls in the case of an accident. The technology was adapted by several OEM, while in 2001 remote vehicle diagnosis and the first real-time traffic information for private vehicles became available. Since then, BMW, GM, Mercedes-Benz, and the Peugeot Société Anonyme (PSA) Group have been the leading adopters of embedded telematics and started to implement emergency and assistance call services into their new launching vehicles[20].

After the implementation of the 3rd generation of wireless mobile telecommunications (3G) connectivity into telematics systems in 2007, the first permanent data connection was introduced by the car brands Dodge and Jeep[6, p. 27]. In 2013 the first 4th generation of wireless mobile telecommunications (LTE) (4G) connectivity was implemented by telematics modules by Audi. A few years later, the EU finalized the legislation in 2016 for making telematics systems mandatory for any newly registered car on the market as of 2018[18]. The next generation of telematics systems will cover 5th generation of wireless mobile telecommunications (5G) connectivity to enable larger and faster data transmissions for further autonomous vehicle & Car2X features. Since nowadays not all vehicles are connected, there must also be solutions to integrate non-connected vehicles into this ecosystem.

2.2.3 On-board Diagnostic System

With OBD-based solutions, vehicles that are not equipped with embedded telematics units can be upgraded with connected car functions[6, pp. 83-84]. OBD is an on-board data access system that was originally designed to monitor engine components[21]. Whereas the first generation of this system originates from the 1980s and had to deal with variations of connectors, interfaces, and protocols, the present generation, OBD-II, was set by the Society of Automotive Engineers (SAE) and the International Organization for Standardization (ISO) in the 1990s. This is based on standardized regulations with only one interface and became mandatory for any car and light trucks by 1996.

OBD-II provides the interchange of digital information between the on-board vehicle network and any device that is connected to the interface. This device is known as an OBD hardware dongle, often supplied with an eSIM that enables connected vehicle functions without an on-board telematics unit.

However, this implies that the vehicle data & functions provided by the OBD-II interface are not made accessible by the OEM, but is processed via an intermediate layer, usually by a proprietary application or service. The open-source OBD-II-based platform “OpenXC”[22], for instance, extends vehicles with a combination of custom applications and pluggable modules.

How manufacturers can use vehicle-related data and what significance this has for the automotive industry is part of the following section.

2.3 Relevance of connected vehicles and their data

All leading car manufacturers have introduced some kind of connected vehicle functions via embedded telematics. Thereby the number of connected vehicles is constantly rising[23].

2.3.1 Distribution and further growth of telematics systems

The Gartner research group expected more than 250 million connected vehicles on the road by 2020. Based on research from Berg Insights AB [20], the total number of subscribers to embedded telematics systems who pay for connected car services, in 2018 was approximately 80 million. In this respect, and at an annual growth rate of around 27 percent, it was expected to reach more than 150 million subscribers in 2020. The worldwide adoption rate of embedded telematics units will increase from approximately 41 percent in 2018, to 82 percent in 2024. Due to the legally obligatory eCall system since 2018 the connected car penetration will hit 100 percent by 2020 for newly registered vehicles in the European Union[24].

The connected car report from 2018 by Statista[6, p. 8] predicts a global number of connected cars 200 million in 2020, and it claims that this number will increase to approximately 340 million connected cars worldwide by 2023.

2.3.2 Data utilization & services today and in the future

The further development of autonomous driving as well as growing in-car services like personal assistants with artificial intelligence (AI), makes it necessary to increase the connectivity of vehicles, as more data needs to be processed[6, pp. 68-69]. Thus, new digital services will emerge from the increasing exchange of data. This will help to shift the cash flows within the automotive industry from vehicle sales to digital & mobility services.

By now, connected car services are mainly offered to car owners by OEM-based brands such as “Connected Drive” (BMW), “Car-Net” (Volkswagen (VW)), “InControl” (Jaguar Land Rover (JLR)), “Mercedes me connect” (Mercedes-Benz), or “OnStar” (GM) and cover common services.

The usual services are listed in the table 2.1 below.

Common OEM offered connected car services	**Description**
OTA-updates	Remote update of vehicle, infotainment & navigation systems
WLAN-Hotspot	Wireless internet access for car passenger
Concierge Service	Assistance for hotel/restaurant bookings & reservations
Diagnostic/maintenance	Monitor car-health related data e.g. remaining engine oil life
eCall	Automatic emergency call
Logbook	Journey/trip logs
Real-time traffic information	Live traffic data
Remote control services	Car functions e.g. door lock/unlock, light, horn
Smartphone infotainment integration	e.g. Android Auto, Apple Carplay
Vehicle status	Read car-related data e.g. battery status

Table 2.1: Common OEM offered connected car services, Source: [25, 26]

However, third-party providers and OEMs are able to use vehicle data for much more. One example is predictive maintenance, which will change the entire maintenance process from a scheduled service plan to an analytical and diagnostic service[6, p. 56]. Based on interconnected components, computing power, and machine learning, vehicles will process a huge amount of vehicle data in real-time and make decisions and take appropriate action according to their current condition. By sharing and combining this information with other parties, the knowledge and diagnostics gained will increase their accuracy and predictability. It is also considered how insights from connected vehicle data and its detailed information can be used for further vehicle development and can be a part of the competition in the automotive industry. In the long term, fewer customers coming to the workshop because of defects helps the image, but in the short term, it reduces costs[27].

The American car manufacturer Tesla uses over billions of recorded kilometer to constantly improve the user experience of their vehicles[28, 29]. Approximately 500,000 vehicles on the road, operate as a neural network that continuously collects data and regularly offers a new driving experience to the customer, with improved features. They train neuronal networks to enhance the ADAS of their vehicles, for instance.

The chairman of VW Group Herbert Diess admits in April 2020[30] that Tesla has a superior software expertise compared to other manufacturers: "*No other car manufacturer can do this today.*"[30].

This implies that there are differences in the use of data of the connected vehicles between the OEMs. As in the example of Tesla, connected car data supports and improves ADAS or virtual assistants based on AI, such as the "Hey, Mercedes" Mercedes-Benz User Experience (MBUX) infotainment system from Mercedes-Benz[6, pp. 68-69].

More data also means higher transmission rates. This has already been initiated with the 5G mobile network standard which encourages Car2X services by interconnecting vehicles and other traffic & road technologies to optimize traffic flow in cities or to exchange weather conditions, for instance[4]. This is a crucial step on the way to self-driving cars and smart cities.

2.3.3 Market perspective for connected car services

The automobile itself is increasingly seen as a touchpoint between customers and the commercial sector. Accordingly, new services such as location based services (LBS) take place on the vehicle, just as it once started with the smartphone [17, p. 14].

The global average annual growth rate of revenues from connected vehicle services is about 21 percent[6, p. 43], which refers only to remote services, safety, and maintenance & diagnostics. As a result, big players from other industries are broadening their spectrum and entering the connected vehicle market such as Allianz, Amazon, bp, IBM, Samsung, SAP, or Deutsche Telekom[31, p. 39].

Otonomo, one of the providers of an independent marketplace for vehicle data from multiple manufacturers, has divided its customers into 12 industries. The figure 2.3 below shows how much each industry sector contributes to its customer base. Industries such as fuel and energy are gradually gaining ground in the use of vehicle data, while other industries such as location intelligence or media research are hesitant[32].

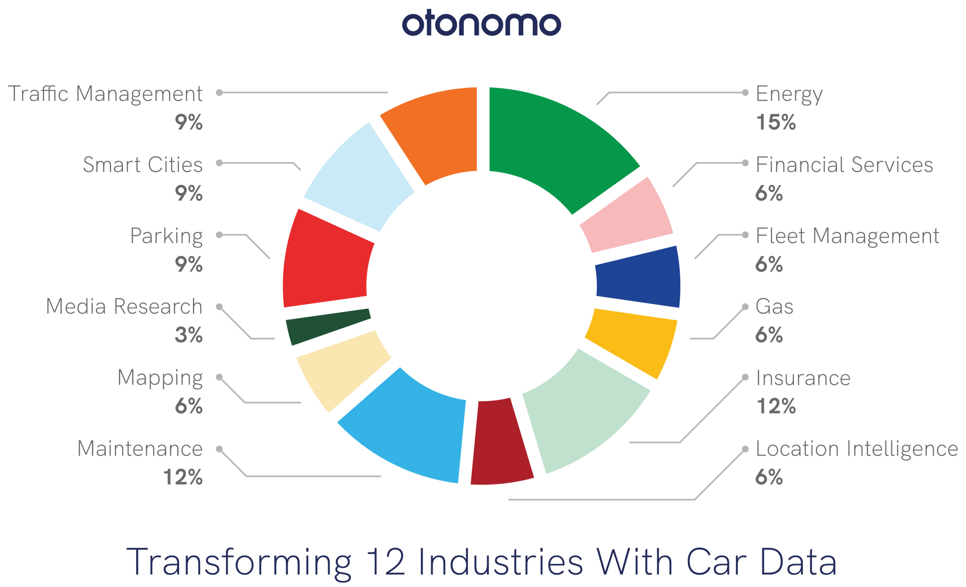

Figure 2.3: Transforming 12 industries with car data, Source: [32]

A market research graph “OtoGraph” from Otonomo displays the maturity level of possible use-cases in terms of the use of vehicle data. According to the graph, half of Otonomo’s customers are willing to use vehicle data for their services. A comparison of personal with aggregate use-cases shows that the classification is quite mixed.

The graph is shown in the figure 2.4 below. The further to the right the use-cases are positioned, the more likely these markets are to rely on vehicle data because they are already positioned in the market or already use vehicle data for their services. Viewed from the bottom up, higher-ranked use-cases are expected to generate more revenue.

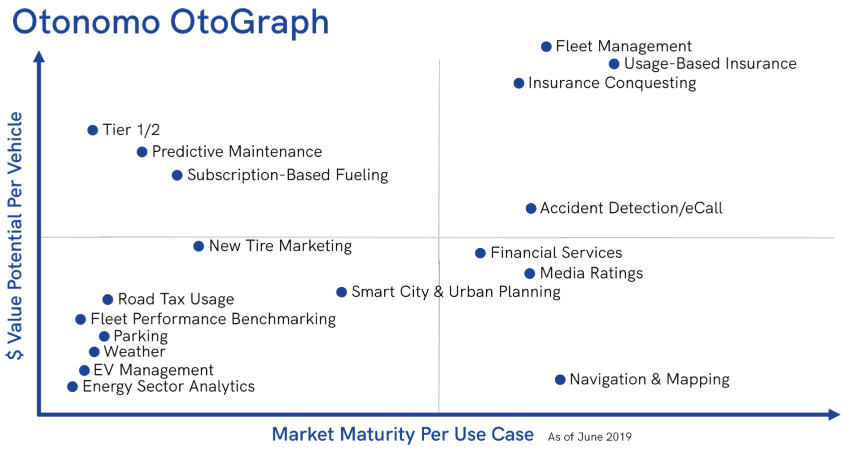

Figure 2.4: Otonomo "Otograph" - market research graph by Todd Brockdorf (Otonomo), Source: [32]

Overall, a large potential is seen in terms of the monetization of vehicle data[6, p. 11,53]. Insurance companies can offer individually tailored policies, workshops can get early access to customers, gas or charging stations can get to know a car nearby that needs fuel or electricity to offer promotions. Besides, OEMs benefit from cost savings by solving recalls related to software problems via OTA updates and shorter development lifecycles due to the collection of operational data. In addition, OEMs have started to offer business solutions such as fleet management[33, 6] based on vehicle connectivity to reduce costs and downtime due to technical problems and to simplify fleet management. In addition, concierge services such as on-demand fueling or car wash and other personal services are potential areas of application[10].

According to Statista[6, p. 41], the global market size for connectivity-based vehicle services was approximately 850 million dollars in 2018 and is expected to grow to a total volume of over 2,000 million dollars regarding remote services, safety/security, and maintenance & diagnostics. The USA is the largest consumer market, followed by China and the European Union as the smallest region in terms of market value and service subscriptions.

2.4 Willingness to share data

According to a survey conducted by Otonomo and SBD Automotive[34, p. 10], nearly 60 percent of European consumers are aware that their car data can be exchanged with manufacturers. Up to 94 percent of connected car service consumers in the USA and 77 percent in Europe show interest in connected car services. In turn, 71 percent of European consumers are willing to share personal vehicle data for the service, depending on its purpose of use[34, p. 17]. There is a solid interest in new services based on connected vehicle data and a high willingness to share their personal vehicle data to gain access to these services. Overall, consumers from the USA are more willing to share vehicle data than European consumers[34, p. 18].

Nearly a quarter of the participants agree to provide their personal data for more benefits to society, especially for smart city & real-time applications to optimize traffic flows, for instance[34, pp. 19-20]. Over half of the respondents would like to share anonymized car data for this purpose. OEMs enjoy high confidence (62 percent) in proper data security, only credit card companies exceed this status (71 percent)[34, p. 36].

Overall, people are willing to share their data and give consent to their vehicle if they see an advantage or an everyday relief through an appropriate service[27, 35]. Third-party providers only need to convince the vehicle owner in their service.

2.5 Standards, guidelines & specifications

This section covers the regulations which are necessary for the data exchange of a connected vehicle. It addresses required commitments and obligations that OEMs and third-parties need to follow to access, process, and protect vehicle data.

2.5.1 The Extended Vehicle concept: an international commitment

For the automotive industry, so far there are not any globally binding rules for handling vehicle data, yet. However, there is a joint commitment with the "Extended Vehicle concept" and the "Neutral server initiative".

Extended Vehicle concept

The Extended Vehicle (ExVe) concept is a framework for off-board vehicle data access via telematics[36]. The ExVe acts as a generic term for the supply, electronic transfer, and use of vehicle-generated data via web interfaces.

This international standardization aims to create a platform, which allows external service providers to retrieve vehicle data in a secure and standardized way to be able to develop and offer new connected car services.

Compared to the on-board data exchange via OBD, ExVe only grants access to defined vehicle data and no direct access to ECUs or the CAN within the vehicle, which means no safety risks can arise regarding data manipulation or misuse. However, the data leaves the vehicle as its origin and is therefore no longer under the direct control of the car owner. The data access is not limited to pure vehicle data, but also covers driver & vehicle generated data (e.g. driving behavior, road condition, maintenance information).

The ExVe concept is still developing and comprises several standardization series:

- ISO 20077: general concept specification in terms of the use of vehicle data via web interfaces
- ISO 20078: requirements for the web services interface according to access control, safety & data content
- ISO 20080: remote diagnostic access for workshop services as its first implementation

Besides the workshop service, further use-cases are in development. The ExVe also forms the technical basis for the neutral server initiative with the web service interface between OEMs & a neutral server institution.

Neutral server initiative

The neutral server initiative was launched by European Automobile Manufacturers Association (ACEA) in 2016, which represents the 15 vehicle manufacturers based in Europe and has the objective of making vehicle-generated data available to third-party services in a secure and independent way[37]. It is especially intended for small to medium-sized companies whose data access is intended to follow a multi-brand approach instead of accessing multiple servers of individual OEMs.

It ensures the protection of the personal data of vehicle owners, the integrity of the vehicle's operation, the liability of the vehicle manufacturers, and intellectual property rights. This implies the following values: customer choice, fair competition, privacy/data protection, safety, security/liability, interoperability & return on investment.

A neutral server is a financially and operationally independent service provider[38] since it is not intended to be a subsidiary of a vehicle manufacturer. Therefore, the OEM provides the possibility of a neutral server to external, independent third-parties through Business-to-Business (B2B) agreements, state-of-the-art security & data protection in the same quality as the data is available on the OEM's server and is delivered without unnecessary delay[37]. Moreover, the data recipient is not known to the OEM, only the data purpose[35].

As a result of data accessibility by neutral servers, OEMs consider on behalf of safety and security to limit the OBD-II interface to the only data which is required for diagnosis, repair, and maintenance. Regarding this, the type-approval of motor vehicles[39] is regulated in the EU as of September 2020 that manufacturers must continue to provide repair-related data in machine-readable form, e.g. via OBD-II, to avoid discrimination against, among others, independent repairers.

However, the neutral server initiative is not mandatory which is why this is implemented to differing degrees by the OEMs. Some are not yet technically able to provide the data to a neutral server[35].

The development and approval of third-party applications may only take place in cooperation with the OEMs based on the B2B agreement with the neutral server. Indeed, third-parties are not able to access data or perform remote control operations such as locking and unlocking doors before passing through the OEM.

This approach provides uniform conditions, allowing fair competition for the development of digital innovation and new business models at the international level. In Germany, the neutral server principle is adapted within the "NEVADA-Share & Secure" (Neutral Extended Vehicle for Advanced Data Access) concept[40].

2.5.2 Global institutions

In addition to non-binding commitments, there are global organizations from the automotive & technology sector that promote uniform rules and standards in processing vehicle data. This section introduces the most important initiatives in the context of a connected vehicle.

The Automotive Working Group

The "Automotive Working Group" of the World Wide Web Consortium (W3C) is a global collaboration of automotive and technology industry participants, in which members of organizations and the public work together. Application developers create web standards to enable web connectivity through vehicle infotainment systems and vehicle data access protocols[41, 42, 43]:

- "Specification for the Vehicle Information Service (VISS)": This is based on the vehicle signal specification (VSS) specification defined by GENIVI and specifies the semantics of the representation of vehicle information via web interfaces.
- "Restful Service Interface (RSI)": This interface is an extension of VISS to provide services via web interfaces and creates a common pattern to be used for services around vehicles.
- "Vehicle Information API Specification (VIAS)": This programming interface makes use of VISS & RSI to provide access to vehicle signals and data attributes.

Car Connectivity Consortium

The Car Connectivity Consortium (CCC)[44] is based in the USA and is linking various sectors like car, telephone, or infotainment system manufacturers and other partners from the industry around the topic of car connectivity.

With "MirrorLink", the CCC builts an open standard for the projection of smartphone applications into the infotainment screens of the vehicle. The consortium also works on other standardization projects for digital vehicle keys and car data.

The CCC follows the approach of creating an industry standard for vehicle data and bypassing proprietary methods via the OBD-II interface and its major drawbacks [45]. This allows all interested parties to participate and exchange solutions with other companies and avoids unfavorable licensing conditions. Similar to other data models the CCC car data model includes the idea of a data marketplace and standardized interfaces for data providers & receivers.

GENIVI

GENIVI was named after its founding location in Geneva and the acronym IVI which stands for the In-Vehicle Cooperation between automobile manufacturers, suppliers, and technology providers for the development and support of connected services[46]. In the meantime, it has become a non-profit alliance of the automotive industry, which focuses on the development of standard approaches for the integration of technology around the connected vehicle[47].

With its "GENIVI Vehicle Domain Interaction Strategy", the alliance focuses on architectures based on connected vehicle data. Besides, it is also addressing the industrial adaptation of Android Automotive[48] and standardized data protocols and consistent human-machine interface (HMI) experiences[49].

Regarding the adaptation of the VSS data model and similar contributors in the context of vehicle networking, the cooperation with W3C is close in order to create a data-oriented connected vehicle architecture.

2.5.3 Vehicle data models

This section describes the common data models that are used as specifications of how the data of a vehicle needs to be structured and processed to be accessible and usable for other parties.

Common Vehicle Information Model

The cross-manufacturer common vehicle information model (CVIM) developed by the "AutoMat" project was originally funded and developed through an EU research and innovation program in 2018[50].

The core intention of the AutoMat project was to create a marketplace for vehicle data in order to exploit the unused potential of information from vehicles of different brands. The interface to the marketplace was derived from a brand-independent CVIM and made vehicle data available to service providers from different industries. AutoMat was intended to reduce the cost of implementing and providing services based on vehicle data.

Since its first introduction the project has no longer been actively developed[51].

SENSORIS – Sensor Interface Specification

The "Sensor Interface Specification" is a group of automotive players from the global vehicle industry, map and data providers, sensor manufacturers and telecommunication operators such as HERE[52], Daimler or Continental, who have joined forces, driven by the common vision to define a suitable interface for the exchange of information between on-board sensors and cloud systems[53]:

- definition of technical specifications for the format & content for uploading sensor and vehicle data
- definition of an exchange format of vehicle-based data for mobility services
- definition of the vehicle-related request format for specific data at specific locations and at certain times

Vehicle Signal Specification

In 2016, GENIVI published the VSS that defines a standardized data description for in-vehicle networks among various car brands[51]. The specification defines over a thousand vehicle signals.

It creates an API for various vehicle-related applications. Meanwhile, the VSS also makes the transmission of data between a vehicle and a cloud extensible and easy to handle.

As the manufacturers' internal networks (CANs) were completely different, the VSS did not lead to the initial goals, as it turned out that it would not be the case that these would be unified by the OEMs. Furthermore, the VSS can be used not only for in-vehicle networks but also for other data exchange between vehicles or cloud-based applications and for any place where the development needs to be shared to open up opportunities for third-party developers and other synergy effects.

Implication Due to the common data communication of various parties, it is essential to use a common data model. The VSS and the SENSORIS are active representatives that come into consideration in the development of connected car APIs and platforms. There are no clear statements in which data models are used by which provider or OEM. In contrast, the ExVe concept also defines the data exchange and is already used by OEMs and connected car platforms. More about this is described in chapter 3.

2.6 Connected car application programming interfaces

In general, APIs connects applications and systems to communicate with each other via defined gateways and enables data exchange based on a common pattern.

Over a hardware component, whether a physical connector or a telematics unit, APIs make it possible to exchange data with the vehicle[3, 54]. They can be applied in various ways to provide access to the vehicle to exchange data for on-board or off-board services. Either via an in-vehicle HMI via the infotainment system or via smartphone apps that can be made available as infotainment substitute or as mirrored smartphone applications, e.g. via MirrorLink. Further possibilities are so-called Termed-Over-The-Top (OTT) systems such as Android Auto[55] or Apple Carplay[56]. However, the OBD interface was the beginning of the establishment of standardized programming interfaces for vehicles.

Stable mobile broadband internet connections, mobile applications, and the IoT make it necessary that car APIs combine all these technologies to open up new possibilities.

To achieve this, there are several platforms from the OEMs itself and independent organization that this thesis deals with.

3 Connected car API platforms

The previous chapter described the fundamentals of a connected vehicle. This chapter explains the definition of a connected car API platform and gives a short introduction to the corresponding platforms which are addressed and compared in this paper.

A connected car API platform provides remote exchange of vehicle data through APIs for car manufacturers, car owners, or service providers to share and integrate vehicle-based data in the form of an open environment[26]. The platforms presented in the following offer an open development and test environment free of charge that enables third-parties to build applications and services around connected car use-cases in a safe and easy way without proprietary hardware such as OBD-II dongles.

Dedicated programming interfaces enable data access and remote control to vehicles via automotive telematics using mobile network communication[19]. Thus third-party providers are able to establish GDPR and other privacy-regulation-compliant solutions around vehicle data[57, 58]. The platforms which are considered in this paper are connecting to vehicles that are equipped with embedded telematics. Therefore, a respective connectivity contract between the OEM and the car owner needs to be in place as well as the permission for data access[59, 60].

In theory, the fields of applications are extensive: car-sharing, emergency services, electric-vehicle charging- or fleet management, in-vehicle package delivery, logbook, mapping, parking, predictive maintenance, subscription-based fueling, usage-based insurance, vehicle measurement, and various smart city services.

The connected car API platforms can be classified into cross-manufacturer and proprietary manufacturer API platforms[61].

The figure 3.1 shows the classification and representative platform providers which were considered for this thesis.

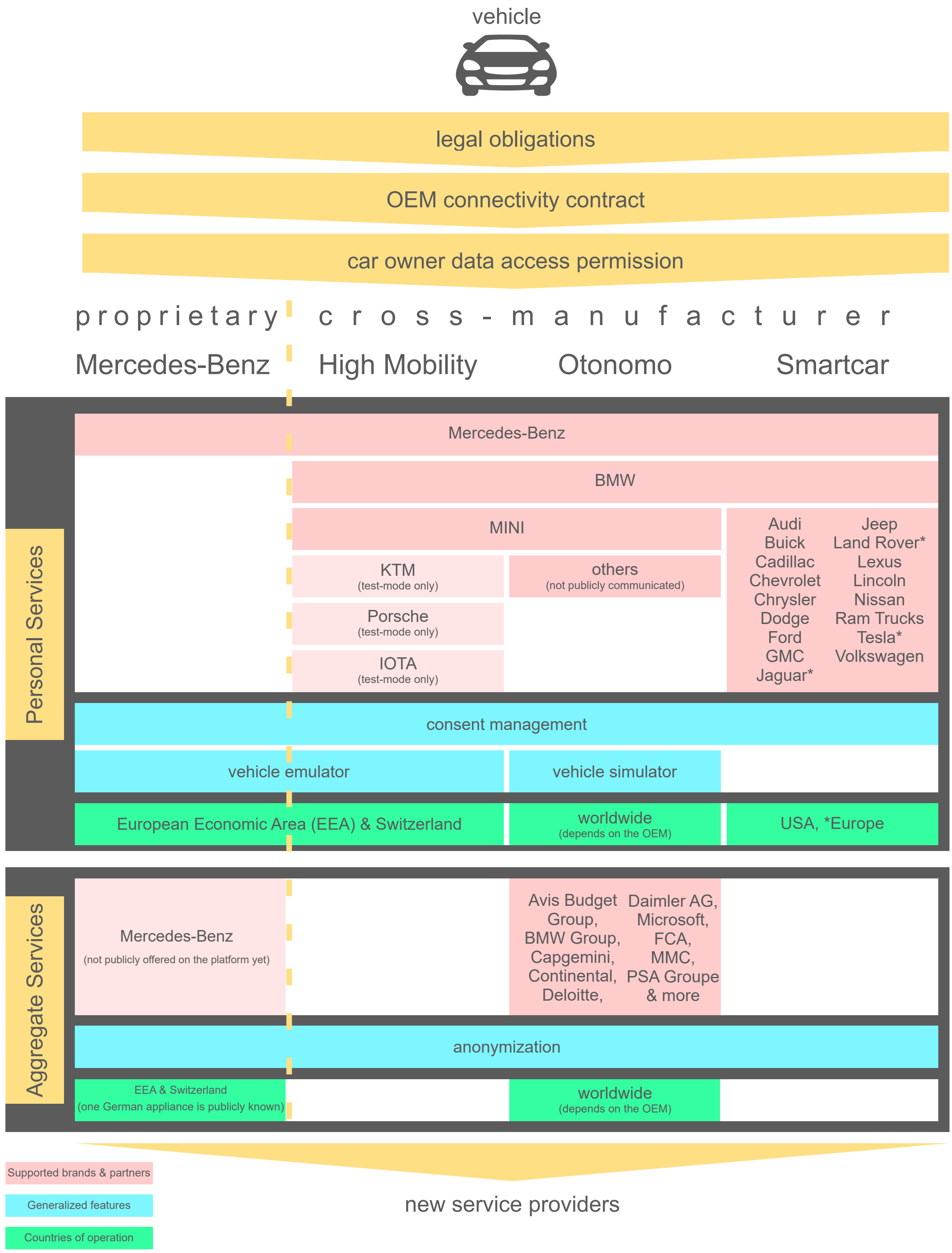

Figure 3.1: General overview of the considered connected car API platforms in this thesis, Sources: [61, 62, 59, 60, 63, 64, 65, 26, 66]

Moreover, it shows the main similarities and differences between the individual platforms with their supported vehicle brands & partners, general features, and countries of operation (CoO). The figure also distinguishes between personal and aggregated service which is important to differentiate the value of vehicle data[61].

3.1 General principle of operation

The principle of any connected car API platform is to offer vehicle data which is provided by telematics from the OEMs. Afterward, the data is prepared to be accessible by APIs for further commercial use, whether the interfaces are used for propriety services of the OEM itself or offered as data products via a platform[33, 27]. The data exchange with the platform and its data products is mainly provided by the most common internet communication technology: representational state transfer (REST)[67]. Other options are provided by software development kits (SDKs) that are designed to simplify the integration of a service or data product. Usually these SDKs are only an abstraction of the existing REST interfaces. A data product bundles one or more API endpoints into a billing unit that represents a pre-defined use-case. An endpoint is used as a synonym for an API whereas on the platforms itself the use-cases are also named as APIs.

The proprietary platforms of OEMs are offered publicly, as in the case of Daimler, or non-publicly, where the data products are invisible and access is only possible on request. Smartcar, for instance, supports 19 different brands[62] with its API although most of the brands do not offer any public data platform for their vehicles. Compared to the proprietary platform of an OEM, a cross-manufacturer connected car API platform adds an additional layer between the vehicle and the third-party data consumer.

The following introduces a selection of proprietary and cross-manufacturer connected car API platforms. More details according to the individual features, vehicle support, technical implementation in detail are described in chapter 4.

3.2 Proprietary manufacturer-specific API platforms

Manufacturer-specific API platforms are provided by the manufacturer itself. The "Mercedes-Benz /developers API platform by Daimler"[66], for instance, is one representative of a proprietary manufacturer connected car API platform.

3.2.1 Mercedes-Benz /developers - The API platform by Daimler

The "/developers" API platform by Daimler[66], is an open data platform which constantly offers new data products for Mercedes-Benz vehicles since its launch in 2017 and has recently reached over 3000 registered developers[68].

The platform provides data access to Mercedes-Benz vehicles from production year 2016 on-wards via REST APIs and mobile SDKs. For this purpose, a development environment with vehicle emulators is provided free of charge and is accessible for everyone to experience these interfaces. In addition to this free sandbox access, the platform also offers the possibility to test the APIs with Bring-Your-Own-Car (BYOCAR) in a real environment.

The specialty of Daimler as a proprietary API platform is, that it also offers APIs for non-connected car-related information such as configuration data or vehicle images which are also available for the vehicle brand "Smart".

3.2.2 Limited availability of public manufacturer platforms

Besides the platform by Daimler, only a minority of manufacturers offer a comparable portfolio of data platforms with public access to a development and test environment around vehicle data without further approval processes.

For example, BMW offers a telematics data platform "BMW CarData"[69], which provides vehicle data of BMW and MINI vehicles but is only intended for service providers who first have to register on the platform with their company data in order to test it. Further examples are the manufacturers Volkswagen and Ford. While Volkswagen offers only a vehicle configurator API "OKAPI"[70] for the latest product, emission and consumption information, Ford is one step further and offers developers early access to the "Ford Connected Vehicle APIs"[71], but is not publicly available yet.

3.3 Cross-manufacturer API platforms

The objective of cross-manufacturer API platforms is to accelerate time-to-market for new connected car-related services based on individual or a pool of vehicle data of various manufacturers through one single interface. This allows third-parties to scale applications and offer services for vehicles of multiple brands without individual contract negotiations and complex API implementation for each OEM. They aim to integrate as many OEM interfaces as possible.

3.3.1 Neutral server as a data marketplace

The principle of integrating the different OEMs into these API platforms is based on the ExVe neutral server concept[37] where an independent organization acts as intermediary between an OEM and a third-party provider defined by ISO standards. Besides that, an uniform protocol like the VSS is required to ensure data flow between each interface.

The figure 3.2 below represents this pattern.

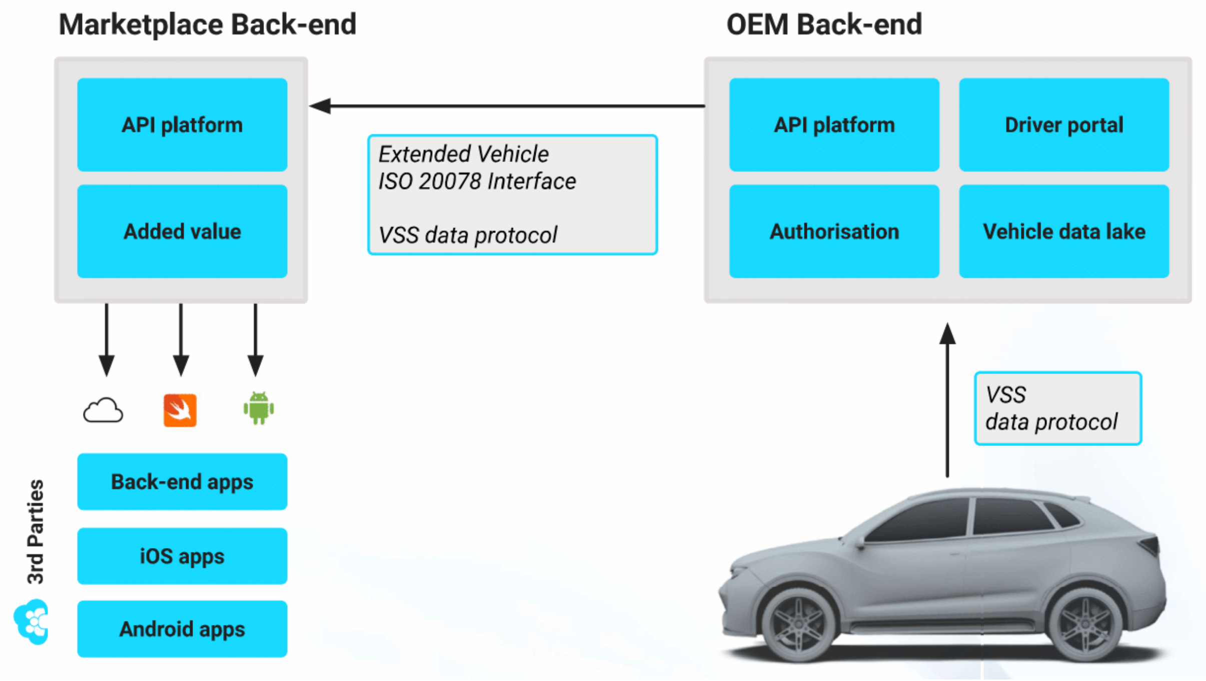

Figure 3.2: OEM server to neutral servers and data marketplaces, Source: [72, p. 13]

The OEM back-end represents the internal environment of the manufacturer where the vehicle data is processed for further use. The marketplace back-end represents the environment of neutral server organizations where the vehicle data is reprocessed and provided as a connected car API platform.

Vehicle data is processed within the vehicle according to the VSS protocol in a uniform pattern and sent to the respective OEM back-end by telematics. Once the data has been transmitted, it can be used by the manufacturer itself or forwarded to neutral marketplaces based on the ExVe interface. Third-party providers are then able to consume vehicle data via generalized interfaces by these marketplaces to develop new applications & services. The authorization and approval flow with the vehicle owner for data access remain on the OEM side.

The following sections introduce three major cross-manufacturer connected car API platforms that offer personal or aggregated vehicle data.

3.3.2 High Mobility - "The vehicle data platform"

High Mobility was founded in 2013 and is based in Berlin/Germany. With an estimated total number of 25 employees the company combines the data access of various car manufacturers and services in one place [26, 73, 74]. Their services are only supported within the European Economics Areas & Switzerland[75, 59, 60].

With its API platform for connected car applications & services, High Mobility implements the ExVe concept and the neutral server principle[38] which provides independent service providers with a secure process for accessing vehicle data of various OEMs via telematics. Therefore the platform offers developers over hundred REST-APIs and a variety of SDKs which are 100 percent open-source[76]. The company also offers a SDK to develop short-range vehicle access with additional hardware via Bluetooth. With the help of a vehicle emulator, High Mobility assists in experimentation and virtual testing during development.

Currently, the services are supported in production for vehicles of the brands BMW, Mercedes-Benz, and MINI[75, 77]. In test-mode vehicles of Mercedes-Benz, Porsche and Kronreif Trunkenpolz Mattighofen (KTM) are available, whereas BMW and MINI are not included. Furthermore, it is also possible to experiment with the IOTA tool which is an open-source distributed ledger technology[78] that uses blockchain-based ledgers to ensure transaction processing[79]. High Mobility operates as a neutral server for BMW, Mercedes-Benz and MINI[38].

According to High Mobility[35] the company will also integrate aggregated data and more OEMs soon.

3.3.3 Otonomo - "The global platform for connected car data"

Otonomo was founded in 2015 and is based in Herzliya/Israel with an estimated number of over one hundred employees worldwide[80, 61].

The API platform provides vehicle data access of more than 20 million passenger and commercial vehicles from 112 countries worldwide, including the USA, Canada, Europe, and Asia via web interfaces only[61, 81]. The "Otonomo Automotive Data Services Platform"[7] gathers data from telematics service providers[1], 15 OEMs including BMW Group, Daimler AG, Mitsubishi Motors Corporation (MMC) & PSA Group, Fiat Chrysler Automobiles (FCA) and 100 ecosystem partners like the Avis Budget Group[61, 83]. Their services distinguish between aggregate and personal data.

The specialty of Otonomo is the supply of aggregated data whereby the platform provides access to historical traffic & road-sign data[7, 84, 61]. Otonomo publicly acts as a neutral server for vehicle brands BMW, Mercedes-Benz, and MINI, but also for other OEMs[85].

3.3.4 Smartcar - "The car API for mobility applications"

Smartcar is based in Mountain View/USA and offers a similar portfolio as High Mobility. The company was founded in 2014[86] and focuses on personalized car applications for reading basic data such as vehicle information, odometer, location, or fuel level but also lock & unlock remote control with the use of web interfaces and various SDKs[87]. The API platform operates for the following car brands across the USA[62]: Audi, BMW, Buick, Cadillac, Chevrolet, Chrysler, Dodge, Ford, General Motors Company (GMC), Jaguar, Jeep, Land Rover, Lexus, Lincoln, Nissan, Ram Trucks, Tesla, and Volkswagen. Smartcar says[64], the company operates in Europe as well, but only for JLR & Tesla vehicles.

Besides a pro-price model, Smartcar also offers a free model that is limited in API calls per month and vehicle [88].

[1] Telematics service providers collect, measure and offer real-time vehicle data like elevation, speed or global positioning system (GPS) information generated by various devices[82].

3.4 Availability of vehicle data

The duration of when vehicle data becomes available within the vehicle and when it is sent and updated on the connected car API platforms depends on the manufacturer, the vehicle and the time of data preparation on the OEM side. High Mobility did a field test with a 2015 BMW i3 model in May 2019[89].

All current BMW models transmit data according to specific interactions with the vehicle[59]:

- at the beginning and end of a journey
- a driver unlocks the vehicle and opens the door
- a driver leaves the car and locks the doors
- while driving: every two minutes or every three kilometers

Regarding these car interactions High Mobility says: "*the updates took about 50 seconds to become available through the API*"[89]. The vehicle must not be driven for data updates. The refresh rate depends on the equipment and production date. Newer BMW models also send data while driving, either every two minutes or every three kilometers, depending on which occurs first.

For Mercedes-Benz vehicles, no official documentation according to the data refresh rate is available. But Mercedes-Benz says[90] that all data points are sent immediately, except for data that is covered by special rules for data protection, such as GPS information. This is updated only every two minutes. Within a few seconds, the data is supposed to be available via the API.

Overall, the refresh rate via the APIs of connected car API platforms like High Mobility is determined by the vehicles and the OEMs. According to the ExVe concept[37] the data have to be delivered in the same quality and speed as it is available to the OEM itself. In the case of Mercedes-Benz, for example, the vehicle data marketplaces access the same APIs that are provided on the proprietary APIs platform[33]. Therefore, no unnecessary delay or loss of quality can be assumed compared to direct access via the OEM platform.

3.5 Distinction to other connected car & data platforms

There is an important difference between connected car API platforms and general connected car platforms such as Amazon Web Services (AWS) for Automotive[91] or the Microsoft Connected Vehicle Platform (MCVP) [92]. The cloud and edge computing services support OEMs to deploy and scale their global vehicle services with its whole technology infrastructure in various automotive scenarios such as OTA software updates, in-vehicle infotainment services, or navigation. These platforms do not offer vehicle access through APIs and do only work in assistance with the OEMs directly[93]. Besides connected car platforms automotive services platforms like HERE[52] or TomTom[94] offer APIs for custom connected car services for in-vehicle infotainment & navigation systems like real-time traffic or parking information, for instance. Other platforms, in turn, refer to these interfaces for their own solutions, as Otonomo does with its aggregated service to offer similar services[61]. But Otonomo also offers remote data access for individual vehicles that connected car service platforms do not. Moreover, vehicle data platforms such as Caruso[95] offer vehicle data of multiple brands, but no open development platform with a test or simulation environment.

4 Technical & business analysis

This chapter points out the similarities and the differences between the individual connected car API platforms. Therefore the cross-manufacturer connected car API platforms High Mobility, Otonomo, Smartcar, and the Mercedes-Benz /developers platform as a representative for proprietary manufacturer platforms were analyzed.

This analysis is divided into a subject analysis, in which the individual platforms are described in detail, while the technical analysis deals with the individual technical implementation from a third-party perspective.

4.1 Subjects analysis

This section is about the connected car API platforms introduced in chapter 3 in more detail and highlights their differences in terms of features, pricing, and their perception in the market. The information is retrieved through literature research and expert interviews within the area of connected car APIs. A summary of the individual expert interviews and their interview guides can be found in the appendix C.

4.1.1 General pre-defined personal use-cases

Before the platforms are described in detail below, it is important to clarify that in the case of personal services, the real-life data release from OEMs to neutral servers is bound to pre-defined use-cases[59, 60, 96, 97]. This is why High Mobility and Otonomo as neutral server organizations refer to official partnerships with the OEMs by the use of ExVe ISO 20078. The pre-defined general personal use-cases available through proprietary and neutral server platforms are the following[97, 96]:

Electric Vehicle Status, Fuel Status, On-Demand Services (e.g. car wash, fueling),
Pay-As-You-Drive (PAYD) Insurance, Vehicle Lock Status & Vehicle Status

The data currently available in real-life, can be found in appendix A.

Data cannot be requested for individual attributes[66] which is intended to prevent data misuse by bundling the data in use-case-related packages[33]. It also simplifies the justification of a data release based on the pre-defined purpose of the data. In the case of Mercedes-Benz, new data products must be approved by internal control committees and data clearing centers to release vehicle data for third-parties. But there are thoughts of providing free configurable attributes which is partly possible by the use of the mobile SDKs[98] with hundreds of data points.

The data release for these use-cases also differs depending on the OEMs. BMW, for instance, provides more than 200 more attributes to Otonomo and High Mobility for the Vehicle Status use-case compared to Mercedes-Benz[97, 59]. This difference may be an indication that the transition to freely configurable attributes is in progress.

4.1.2 High Mobility

High Mobility presents itself as a vehicle data marketplace and a neutral server provider for various OEMs made by developers for developers[26, 35]. They are specialized in accessing personal vehicles that are linked to a specific VIN.

The target groups are insurance companies, fleet operators, car-rental & car-sharing companies, e-mobility providers, and maintenance environments like dealers & workshop chains. One insurance example is "Pay-drive" which offers PAYD services based on High Mobility telematics data[99]. Another example is "Vimcar" that offers an electronic logbook and started to implement telematics data by High Mobility besides OBD-II-proprietary hardware dongles[35].

However, High Mobility also engages activities in the field of anonymous aggregated data, which are expected to come onto the market in the course of 2020[35]. Currently, there are plans for real-time data to track fleet vehicles (rental vehicles), for instance. In addition, there are also plans to share data for damage claim settlement to analyze accident & breakdown data of vehicles to make rough damage calculations. High Mobility says[35], that it is known, that some OEMs are willing to share this data. Nevertheless, aggregated data will not be the main focus compared to the personalized vehicle data that is already offered.

With its so-called "Auto API"[100] High Mobility provides an open-source interface that translates the data format of each supported OEM into one unified protocol to offer vehicle data access. The basis for this is the standardized cross-manufacturer customer consent flow which allows vehicle owners or third-party providers to grant or deny the data access to vehicle data across multiple OEMs[77]. The required data can be selected from pre-defined data sets or individual data points. With so-called "Webhooks"[101] High Mobility also offers pre-defined trigger subscriptions to act on various vehicle events. Batch requests or multi commands are reserved for the Android[102] mobile SDKs only[103]. Moreover, the platforms offer data access via Bluetooth technology which has emerged from history and is not the focus of their portfolio anymore but is still a maintained service especially for customers who are using the product as part of their own telematics solutions with proprietary hardware[35].

For the development of third-party applications, the platform supports with a sandbox testing environment including a vehicle emulator and pre-recorded, configurable simulations of various scenarios such as an accident. In fact, the vehicle emulator environment itself is also part of the product portfolio on request but is not publicly offered as a product. For instance, Mercedes-Benz has officially implemented the "powered by High Mobility" vehicle emulator for its own API platform[104].

Once the development of an application is completed and ready for production, the sandbox application must be registered as a productive application and provided with additional information such as the end-user terms of the product, privacy policies, and payment information to verify the terms of use of the vehicle data[105]. Afterward, the app is checked for compliance with the privacy policies, GDPR, and the right implementation of the consent flow[35]. In addition, the transparent access to the terms and conditions of the service and the intended purpose of the provided data are verified. After approval, the credentials for the authentication within the application needs to be changed to start getting customer consent to process real-live vehicle data.

Pricing

The pricing for real-live data in production differs according to the use-cases[106]. These use-cases are the most demanded products, which include various API endpoints. For instance, the electric vehicle (EV) charging use-case implements the endpoints for the battery level and the estimated remaining range. However, the available data differ depending on the manufacturer. Mercedes-Benz, for example, only allows access to the mentioned endpoints in the EV charging use-case, while BMW vehicles also have access to the charge state, the plugged-in state and the charge voltage of the respective charging station. Due to the wide variation of accessible data even within the use-cases, the prices differ across the manufacturers as shown in the table 4.1. This is caused by the manufacturers and therefore it is not possible to create a consistent price model[35].

Account	API / Use-case	Supported vehicle brands	Price	Per number of requests	Accounting per
Starter[1]	EV Charging	BMW, MINI	1.95 €	1	min (max. 50 requests/min)
		Mercedes-Benz	0.29 €	2	hour (max. 2 requests/hour)
Starter[1]	Logbook	BMW, MINI	1.17 €	1	min (max. 50 requests/min)
		Mercedes-Benz	n.a.	-	-
Starter[1]	PAYD	BMW, MINI	0.39 €	1	min (max. 50 requests/min)
		Mercedes-Benz	2.10 €	2	day (max. 2 requests/day)
Starter[1]	Predictive maintenance	BMW, MINI	0.78 €	1	min (max. 50 requests/min)
		Mercedes-Benz	n.a.	-	-
Enterprise[2]	custom	custom	1,499.00 €	-	month

[1] On-demand pricing
[2] Includes data for hundred vehicles

Table 4.1: High Mobility pricing, Sources: [106, 59, 60]

High Mobility offers on-demand pricing in a starter account, but discounts according to the monthly requested vehicles, and a customized pricing policy for companies or start-ups are possible. The test environment and all the provided SDKs, documentation and support via mail, forums and Slack channels are free of charge. In addition, the Enterprise account offers personal assistance via developer support, on-boarding, workshops & project management for integration. Moreover this includes the possibility of real-live access of hundred vehicles by the third-party application.

4.1.3 Mercedes-Benz /developers

The connected car API platform "/developers" by Daimler offers data products from Mercedes-Benz vehicles to other companies and organizations, so they can develop or improve applications or services based on these data[33, 66].

The customer base is diversified and ranges from independent Mercedes-Benz dealers to automobile clubs or start-ups, especially for vehicle diagnostics. But also individual developers are using it to develop applications for Mercedes-Benz vehicles. Indirectly, it is tended to strengthen innovation in Connected Car Services and visibility as a brand[33]. Based on legal motivations, the intention is to make the data available as a forerunner, as this may become mandatory in the future. The European institutions regularly call for the opening of vehicle data, but if there is no significant customer demand for it, the data is not released, explains Mercedes-Benz[33].

In 2016, Daimler started the "OneAPI"[107] initiative to open up digital services for external use by facilitating cooperation between partners. The developers platform followed in 2017 which was the first approach to share vehicle data with third-party application developers. Meanwhile, the platform is structured into two general parts[33]:

- OneAPI: the internal API management environment for vehicle data
- OpenAPI: this represents the open /developers API platform and is built on top of the OneAPI

According to Mercedes[33], the purpose of both parts is to offer data products on B2B or Business-to-Municipalities (B2M) level. But also individual developers are welcome to the platform.

On B2B level, the focus is on the monetization of vehicle data and cooperation with other organizations to develop new personal vehicle-based applications[33]. The customer portfolio is widely diversified, from independent Mercedes-Benz dealers to automobile clubs or startups. They are especially interested in vehicle diagnostic data.

First-hand aggregated data

Due to the high demand, Mercedes-Benz is also addressing B2M customers regarding aggregated data which is heading for smart cities and road/traffic conditions information like potholes or accidents[33]. Anonymized vehicle data is provided to towns or local authorities to increase road safety. The Zollernalbkreis district in Germany uses Mercedes-Benz vehicle data to enable targeted use of winter road clearance services and optimization of road salt application, for instance[65, 33]. In fact, this is missing in the OpenAPI /developers-platform portfolio but is already offered via the non-public OneAPI. According to Mercedes-Benz an open data product is in development which will also be provided to cooperation partners like HERE[33]. More data products like fleet management and other aggregated services will find its way on the OpenAPI platform soon.

BYOCAR - Bring-Your-Own-Car

Individual developers are also interesting for the platform to support and push the development of applications around Mercedes-Benz vehicles. Since June 2020, the manufacturer offers with BYOCAR[108] a limited free option for test purposes with real vehicles. The process costs for the B2B approval are very high, which is why individual developers with great ideas have had to be rejected so far. With BYOCAR, individual developers and companies are able to test the data products with their real vehicles free of charge without approval procedures. However, the data access is limited but there is no information to what extent the data is limited.

The mobile SDKs[98] for the operating systems Android[102] and iOS[109] provide ready-to-use implementations such as user authentication, vehicle assignment, or service activation to focus on the vehicle data and functions around the car data.

Besides the free-of-charge sandbox test environment and BYOCAR, the platform offers a trial tier for non-connected vehicle data. The business tier represents the productive paid access to real-live data which represents only personal services yet. An overview of the availability of each use-case is shown in the table 4.2.

	Tiers			
API / Use-case	**SANDBOX**	**BYOCAR**	**TRIAL**	**BUSINESS**
Car Configurator[1]	☑	☐	☑	☑
Electric Vehicle Status	☑	☑	☐	☑
Fuel Status	☑	☑	☐	☑
PAYD Insurance	☑	☑	☐	☑
Remote Diagnostic Support[2]	☑	☐	☐	☑
Remote Maintenance Support[2]	☑	☐	☐	☑
Vehicle Images[1]	☑	☐	☑	☑
Vehicle Lock Status	☑	☑	☐	☑
Vehicle Status	☑	☑	☐	☑
Connected Vehicle[3]	☑	☐	☐	☐
Finance calculator[3]	☑	☐	☐	☐

[1] car brand 'smart' vehicles are also supported
[2] busses, trucks & vans are also supported
[3] Status: experimental

Table 4.2: Mercedes-Benz /developers pricing tiers, Source: [110]

Pricing

According to Daimler[33] the pricing of the /developers platform is still pending. How it is structured is seen in the table 4.3. Daimler offers volume-related discounts and special startup conditions in the initial phase of the company[33].

The /developers platform is provided by the Daimler AG subsidiary Mercedes-Benz Connectivity Services GmbH[1], which is responsible for the sales of the APIs, except for the Remote Diagnostic Support (RDS) & Remote Maintenance Support (RMS). These APIs need to be offered by the vehicle manufacturers organization itself[33] according to ExVe ISO 20080 specification[112]. Therefore RDS & RMS are offered via the XENTRY Shop[113, 114, 33] provided by the Mercedes-Benz AG.

Tier	API / use-case	Price	Per vehicle	Per no. of call	Accounting per	Restrictions
SANDBOX	all	free	-	-	-	-
TRIAL	Car Configurator	free	~	150	call	limited to 150 calls
BYOCAR	[*]	free	1	~	-	limited data access
BUSINESS		0.19-0.39 €	1	1	month	individual[1]
BUSINESS	Remote Diagnostic Support	5.99 €	1	1	call	valid for 90 days
BUSINESS		54.00 €	1	10	call	
BUSINESS		544.99 €	1	100	call	
BUSINESS	Remote Maintenance Support	3.49 €	1	1	call	valid for 90 days
BUSINESS		31.99 €	1	10	call	
BUSINESS		314.99 €	1	100	call	
TRIAL	Vehicle Images	free	-	-	call	limited to 5 calls
BUSINESS	Vehicle Images - Flexible	2.90 €	1	1	picture	-
BUSINESS	Vehicle Images - Basic	15.90 €	1	10	picture	-
BUSINESS	Vehicle Images - 360°	24.90 €	1	40	picture	-

* API / use-case: Electric Vehicle Status, Fuel Status, PAYD Insurance, Vehicle Lock Status, Vehicle Status

[1] Limitation depends on the use-case: 1call/hour (Fuel Status), 2 calls/hour (Electric Vehicle Status, PAYD insurance), 50 calls/hour(Vehicle Status, Vehicle Lock Status)

Table 4.3: Mercedes-Benz /developers pricing, Source:[110, 113, 114, 33]

[1]Mercedes-Benz Connectivity Services GmbH is a subsidiary of the Daimler AG and is a digital & vehicle connectivity services provider that is responsible for product development, operations, and sales & marketing for commercial connectivity and fleet telematics services[111]

4.1.4 Otonomo

In terms of the number of employees[80] and a database of 20 million vehicles, Otonomo is the largest provider of connected vehicle data and focuses on aggregated services. Moreover, the platform relies on 330 billion tracking miles (~530 billion kilometers) from over a hundred countries according to their statements[61]. Data suppliers are OEMs but also other data suppliers that benefit from license fees from Otonomo as a client.

Platform operation

The Otonomo platform technology reshapes all the collected data from multiple sources and makes it available for applications & services in a secure way while ensuring compliance with legal regulations and drivers privacy with the use of machine learning[2][61]. Otonomo operates as a neutral server for the car brands BMW, MINI Mercedes-Benz, and others, which according to their own statements may not be mentioned by name.[85].

With its "Otonomo Consent Management Hub"[116]-app the company provides a process to manage the permission for data consumption of personal service. This validates driver consent with each personal data request from third-party service providers by providing consumers the control to grant and revoke consent to their data and is intended to ensure transparency. According to their own statements, it is also supposed to be possible to differentiate and adjust the settings for individual drivers. But it is not clear how this app is supposed to be used in a productive environment with vehicle owners and third-party providers. Moreover, the self-creation of personal services via the consumer platform is under development[117] as well as the streaming interface[118], whereas this needs to be requested specifically.

For the aggregated services the data anonymization is performed by the "Otonomo Dynamic Anonymization Engine"[119]. This managed service is implemented in either the OEM or the data provider's IT environment to ensure that no data flow occurs without anonymization. Personal related data such as vehicle identification and driver information are made unrecognizable by manipulating VIN, location accuracy, location frequency, and trip data. These procedures can be adjusted to the requirements of the individual data provider, consumer, or according to local regulations.

Moreover, Otonomo provides various methods to consume data[120, 121, 118]: via a user interface within a web browser and via APIs. Furthermore, webhooks provide vehicle data based on pre-defined vehicle events but are also provided by the APIs. The user interface is accessible via Otonomo's consumer playground of their platform. In addition, a streaming option provides data based on pre-defined intervals and conditions.

From a developer's point of view, the platform offers a playground with pre-defined aggregated and personal services for testing. A car simulation of a driving vehicle and pre-defined events supports the testing of the APIs. But there is no car emulator that can be manipulated for experimental purposes like in the case of High Mobility and Mercedes-Benz. Regarding aggregated data, the APIs can be tested by requesting and downloading reports.

[2] "Machine Learning is the study of computer algorithms that improve automatically through experience."[115]

Perception

In 2018, Otonomo was named as a “Cool Vendor” in the “Cool Vendors in Automotive and Smart Transportation” research by the Gartner[122, 123]. Statista claimed in its “Connected Car Market Report 2019”, that Otonomo “*provides the first neutral platform for gathering, aggregating, and editing vehicle-related data by various OEMs*”[6, p. 50]. By the end of 2017, the company was able to acquire over 75 customers for its platform. With regards to monetization of vehicle data, Otonomo can be seen as a competitor to tech giants like Google. However, the company does not collect or use the data itself but gathers it from other data providers to provide it to the whole industry in comparison to the technology giants. According to Statista[6, p. 50], Otonomo will be an important player for vehicle data monetization in the future due to their extensive partnerships and the advantage of an independent platform. But there is no publicly communicated third-party service that is offering its services based on Otonomo yet. However, Otonomo and Capgemini, a global leader in consulting, digital transformation, technology, and engineering services, announced a collaboration to help customers with new products & services based on vehicle data[124].

Use-cases

Besides the general personal use-cases, Otonomo offers anonymized vehicle data for aggregated services. These can be generalized in the table 4.4 as follows.

Aggregated use-cases	Description	Potential implementation
Smart Cities	Optimization of traffic & route flows, transportation & parking systems, emission management	Traffic light interval improvement, real-time traffic information (RTTI)
Mapping & Planning Solutions	Up-to-date maps, traffic movement information, monitoring period of time in specific areas for commercial sites	Up-to-date maps
Location Intelligence	Analyse market research, shopping behavior, parking situations	Improve campaign effectiveness, park-spot information
Media Research	Read consumption patterns within the vehicle	Targeted advertising, product recommendations

Table 4.4: Otonomo aggregate use-cases, Source: [9]

Pricing

The pricing of Otonomo’s vehicle data is divided into a pay-per-use and a custom plan. The pay-per-use model includes a 30-day trial free of charge for a restricted amount of data. Personal use-cases are not available through the pay-per-use model. But access to aggregated data is also limited. A custom plan needs to be requested individually to access more data.

An overview is shown in the table 4.5.

Account	API / use-case	Price	Vehicles	Number of requests	Accounting
Pay-per-use[1]	during 30 days trial	free	~	10,000	data points
Aggregate Data Service		free	~	200	trips
Pay-per-use[1]	after 30 days trial	60$	~	1,000,000	data points
Aggregate Data Service		60$	~	20,000	trips
Custom Plan	Aggregate Data Service & Personal Service	custom	custom	custom	custom

[1] Pay-Per-Use restrictions:
- Only standard car data attributes
- Only aggregated service data except road sign- & ultrasonic sensor data
- No events, no streaming & limited amount of countries and use-cases
- Service creation limit up to five created services
- Limited data range of reports up to seven days

Table 4.5: Otonomo pricing, Source: [125]

4.1.5 Smartcar

Smartcar claims its platform is the first and only car API for mobility applications[126]. It offers vehicle data access for personal connected car services only.

With its so-called "Smartcar Connect"[62] a third-party application can link a personal vehicle from all supported brands. This is also part of their SDKs and makes other brands automatically compatible with a Smartcar-based application once they become available on the platform. This also integrates the consent management to let customers grant or deny data access or remote control to the vehicle.

Smartcar differs between two types of API requests: application-triggered API calls and batch requests[127]. The second variant offers the request of multiple API calls simultaneously with one single request. For example, retrieve a vehicle's odometer and fuel tank level at the same time. Moreover, webhooks for scheduled retrieval of data collection in pre-defined time intervals are supported[128].

Via an optional compatibility-check API Smartcar is able to verify the eligibility of a car, based on its VIN[88]. With "Connect Match" & "Connect Direct" Smartcar offers features for more end-user comfort of the third-party app. Thus, this allows car owners to link a specific vehicle of already known vehicles or skipping the brand selection in the authorization flow.

Smartcar clustered its customers into the fields car insurance, car-sharing, energy & utilities, EV charging networks, fleet management, and on-demand car services such as car wash or fueling[87]. For each industry, real references are listed which are startups that count on the vehicle integration into their services through Smartcar-APIs. A few examples are "Pitstopp", a cloud-based fleet management, or car-sharing platforms like "Naboli" or "Turo". Paydrive, which also cooperates with High Mobility, is also part of their references.

Pricing

As shown in the following table 4.6, Smartcar is one of the few platforms to offer a free account for limited requests & vehicles in one month which is mainly possible for customers from the USA yet.

Pricing plan	**API / Use-case**	**Supported vehicle brands**	**Price**	**Vehicles**	**Number of calls**	**Accounting per**
Free[1]	any	[*]	free	3	50	call/vehicle/month
Starter[1]	any		5$	100	200	
Pro[2]	any		7$	unlimited	500	
Enterprise	any		custom	unlimited	custom	annual commitments

[*] US support: Audi, BMW, Buick, Cadillac, Chevrolet, Chrysler, Dodge, Ford, GMC, Jaguar, Jeep, Land Rover, Lexus, Lincoln, Nissan, Ram Trucks, Tesla, Volkswagen;
Europe support: Jaguar, Land Rover, Tesla

[1] Restricted features and customer service

[2] Restricted customer service

Table 4.6: Smartcar pricing, Source: [88]

With the chargeable pricing plans, more vehicles can be addressed. The free and starter pricing plans are restricted in features and customer support. For example, it is not possible to use webhooks and batch requests. Furthermore, the availability-check-API is not available. The pro pricing plan ensures guaranteed mail and chat support within 24 hours, whereas the enterprise custom plan also includes phone support, a customer success manager, and an on-boarding program.

Distinction to other platforms

The official use of vehicle data is tailored into pre-defined use-cases by the OEMs. Smartcar is not committed to these use-cases, which implies that the vehicle data is not based on official partnerships with the OEMs. Nevertheless, connected car services are made possible by unofficial APIs that were developed by reverse engineering. In the case of Tesla, for instance, several privately reverse-engineered APIs are available on the internet to develop connected car features[129]. This assumption is underlined by an employee in the area of internal vehicle API development at JLR[27] who confirms that there is no partnership with the manufacturer although Smartcar officially supports JLR vehicles with their interfaces[62].

From this follows a further distinction that Smartcar is the only provider where the application can be switched to live mode by changing a single attribute without additional approval[130].

4.2 Technical analysis

By analyzing and handling various interfaces of the introduced connected car API platforms, this section points out how the platforms distinguish in their technical implementation from a third-party point of view. For this purpose, a simple web application was created, that implements some of the basic APIs of each analyzed platform. An impression of the web application can be found in the appendix D. This was used as a basis for a technical evaluation following a selection of various guidelines & specifications in interface design to analyze the practicality and usability of the programming interfaces.

The selection of the evaluation criteria is a summary in accordance to W3C, Microsoft, and others. A list of all criteria is found in section 4.2.7

To obtain any kind of vehicle data or vehicle communication via a connected car API platform, a registration on the platform is required in advance to identify the third-party consumer. To make the development of new services and applications around vehicles as easy as possible, it is free of charge and open to everyone. This allows experimenting and testing with the platforms with no boundaries.

The following section describes the process of obtaining permission to use vehicle data via a connected vehicle API platform.

4.2.1 Obtaining authorization

After the registration on the platform is done, the so-called "ClientID" & "ClientSecret" is created for the account. These are confidential authorization credentials that are bound to the respective account and are also used for accounting purposes when a third-party service based on the respective platform is launched. Consuming data from the individual platforms, needs authentication and authorization for a third-party service. For this purposes, Open Authorization (OAuth) 2.0 (RFC 6749)[131] is used to verify the identity of an inquirer and obtain the permission to get access to vehicles data or remote control.

Since this is used on all considered platforms, an uniformed process can be generalized on the basis of the OAuth "Authorization Code Grant" specification and the individual platform's implementation[132, 133, 134, 135].

The OAuth "Authorization Code Grant" is mandatory to get access and grant consent for personal services based on the ClientID. For this purpose, the platforms provide mechanisms to request the necessary approvals directly from the manufacturer. The vehicle owner has to login to the car manufacturer's connectivity service and grants the necessary permissions. If the login is successful the authorization server replies with an authorization code and redirects the user back to the application whereas the application requests to exchange the received authorization code with an access token. After the third-party application's server/back-end gained the access-token, the application is authorized and able to call APIs against the resource server, the connected car API platform in this case.

The common pattern is shown in the figure 4.1 below.

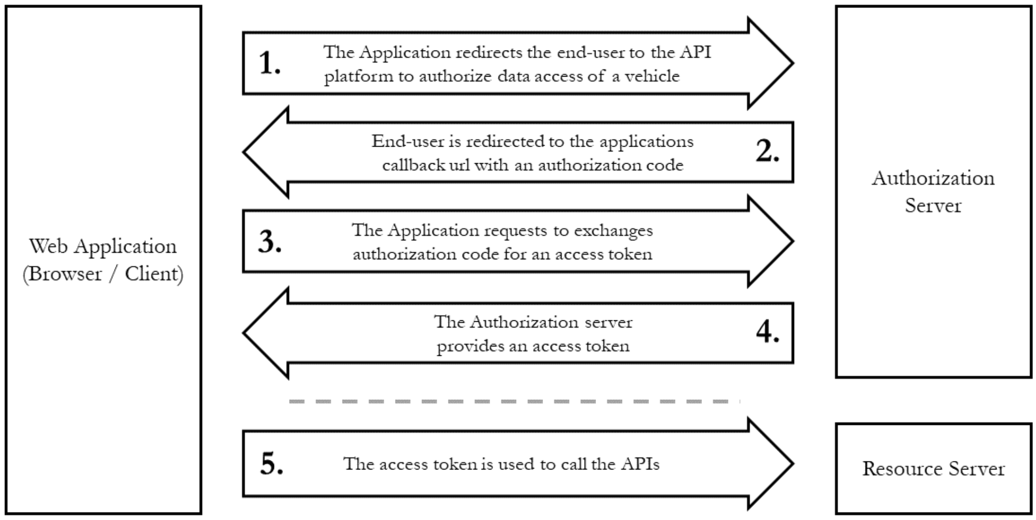

Figure 4.1: Uniformed OAuth authorization code flow, Source: Adapted from [133][131, Fig. 3]

On the other hand OAuth also offers the option to obtain authorization via "Client Credentials Grant" as shown in figure 4.2, which is used to authorize and authenticate a system rather than a user. This comes into play if the data is not related to an individual vehicle and user consent is not required to request anonymized aggregate data[136, 135]. Therefore the credentials are provided by the platform via the ClientID & ClientSecret combination or other authorization values for requesting an access-token. Once authorization and permissions are granted, vehicle data can be requested.

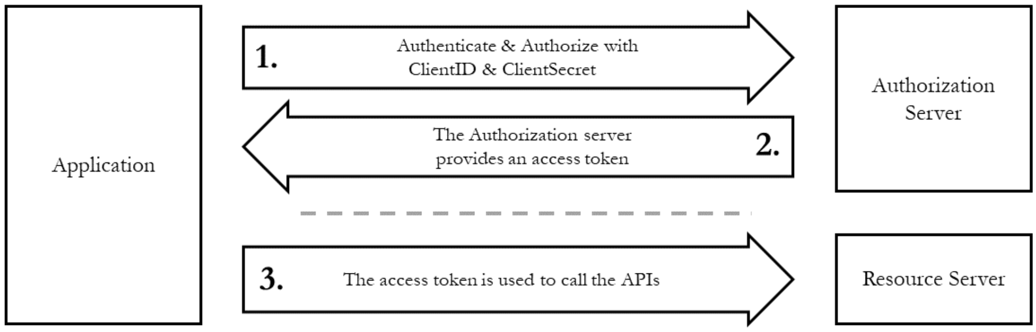

Figure 4.2: OAuth client credentials flow, Source: Adapted from [131, Fig. 1]

4.2.2 Implementation setting

The gathered experiences of implementing some APIs of each featured platform show the differences in integration and handling the APIs within a web application. For each platform, the most convenient way of implementing from the developer's point of view was used. While all platforms offer REST APIs, some others offer a variety of SDK to support developers in using the platform as easily as possible.

In the beginning, a basic web application was set up by using the font-end web-library React[137] and Node.js[138] which is seen in the appendix D. React is made for building dynamic user interfaces based on the script programming language JavaScript[139]. It was chosen since all platforms offer libraries and examples for this script programming language. Other than that, also the runtime environment Node.js is based on JavaScript. This represents the back-end of the application and is the original base where the API implementations take place. Moreover, Node.js comes with an open-source package ecosystem, the Node Package Manager (npm)[140], which provides easy integration of SDKs and other software libraries. In the following, the experiences with the implementation process of the individual platforms are described.

4.2.3 High Mobility implementation

High Mobility offers a variety of SDKs, either for the mobile operating systems Android[102] & iOS[109], but also to create web applications with Node.js or REST. The easiest way to implement the High Mobility Auto API for web applications is the use of the open-source Node.js SDK "HMKit" from GitHub[3][142] or provided by npm[143].

The platform can also be tested without any implementation by the use of the ready-to-use Postman[144] collections that can be downloaded on the platform's application setup. In development-mode, any kind of implementation or data requests are free of charge.

Before High Mobility's Auto API is ready-to-use, the application needs to be configured on the platform. The permission setup lists all available attributes that possibly can be queried for the use of the application. Additionally, High Mobility also lists the real-life available attribute of the supported OEMs.

A video-assisted Node.js tutorial[145] with code snippets guides through the application setup and the initial connection from the application onto the platform. For development support, High Mobility also offers a developer forum, a support channel via Slack[4][146] and a variety of examples on GitHub or medium.com[147].

The OAuth-process can be done by the client credential flow, as described in figure 4.2, where the vehicle and application are pre-defined on the platform. When the HMKit SDK is initiated using the ClientID and ClientSecret, an access certificate is generated by the platform as a response to link the application accordingly.

The other way is the dynamic implementation by the authorization code flow, as explained in figure 4.1, where the consent flow allows to delegate the authentication to the respective vehicle to the end-user to select the respective vehicle and grant data access[132].

[3]GitHub is a network-based version control service for software development projects[141].
[4]Slack is a collaborative business communication platform

The first approach takes the advantage that no OAuth-process needs to be implemented and a developer can start interacting with the APIs immediately, but the application end-user is not able to change the linked vehicle. On the second approach the OAuth-process by using the HMKit-SDK does not offer much relief compared to standard OAuth implementation. Furthermore, this is not described for Node.js, but can be adapted from the OAuth documentation of other provided SDKs.

The following example 4.1 shows the OAuth-flow according to the user consent flow where the account gets authorized against the platform via the ClientID & ClientSecret. In this example the request is made by the hypertext transfer protocol (HTTP) client Axios[148]. The app itself gets authorized via private keys (hmAuth1Key, hmAuth2Key) which also can be found on the applications settings page. Afterward, the HMKit gets initiated and the access certificate can be downloaded.

```
const axios = require('axios'); //initialize http client
const HMKit = require('hmkit'); //initialize  High Mobility API
var hmkit = '';
var access_body = '';
var accessCertificate = '';

const code = res.req.query.code; //save the auth-code from the server response

return axios
  .post(tokenUri, {
    client_id: clientId,
    client_secret: clientSecret,
    redirect_uri: redirectUri,
    grant_type: 'authorization_code',
    code: authCode
  })
  .then(async (response) => {
    access_body = response.data
    hmkit = new HMKit(hmAuth1Key,hmAuth2Key); //link High Mobility API with application
    accessCertificate = await hmkit
        .downloadAccessCertificate(access_body.access_token) //download access certificate
    res.send(access_body) //send response back to the font-end
 });
```

Code example 4.1: High Mobility OAuth HMKit SDK example

Once the access certificate is downloaded by providing an access-token the HMKit is read-to-use as seen in the code 4.2:

```
const response = await hmkit.telematics.sendCommand(
     // command helper function via the SDK to unlock vehicle
    hmkit.commands.Doors.lockUnlockDoors({ locksState: 'unlocked' }),
    accessCertificate
);
```

Code example 4.2: High Mobility unlock HMKit SDK example

The response of this door-unlock command request can look like the example 4.3 below. The response of a successful request sends the respective latest data as a success state. Typically, a JSON format[149] is used to structure data of the responses.

```
"positions": [{
        "value": {
            "location": "all",
            "position": "open"
        },
        "timestamp": "2020-05-07T14:57:00.778Z"
    }
]
```

Code example 4.3: High Mobility unlock HMKit SDK response example (simplified)

The Node.js Auto API via the HMKit offers various commands[150] that are provided as a parameter within the function `sendCommand`. As a second parameter, the access certificate holds the authorization details so that a command is sent to the respective vehicle. All the commands can also take over parameters if necessary, such as the locks-state like in the example 4.2 above. All commands are implemented as asynchronous functions which means that the application is waiting for a response of the platform or the vehicle respectively.

As a relief for debugging, all API interactions are logged as a feedback in a vehicle emulator on the platform, as seen in figure 4.3.

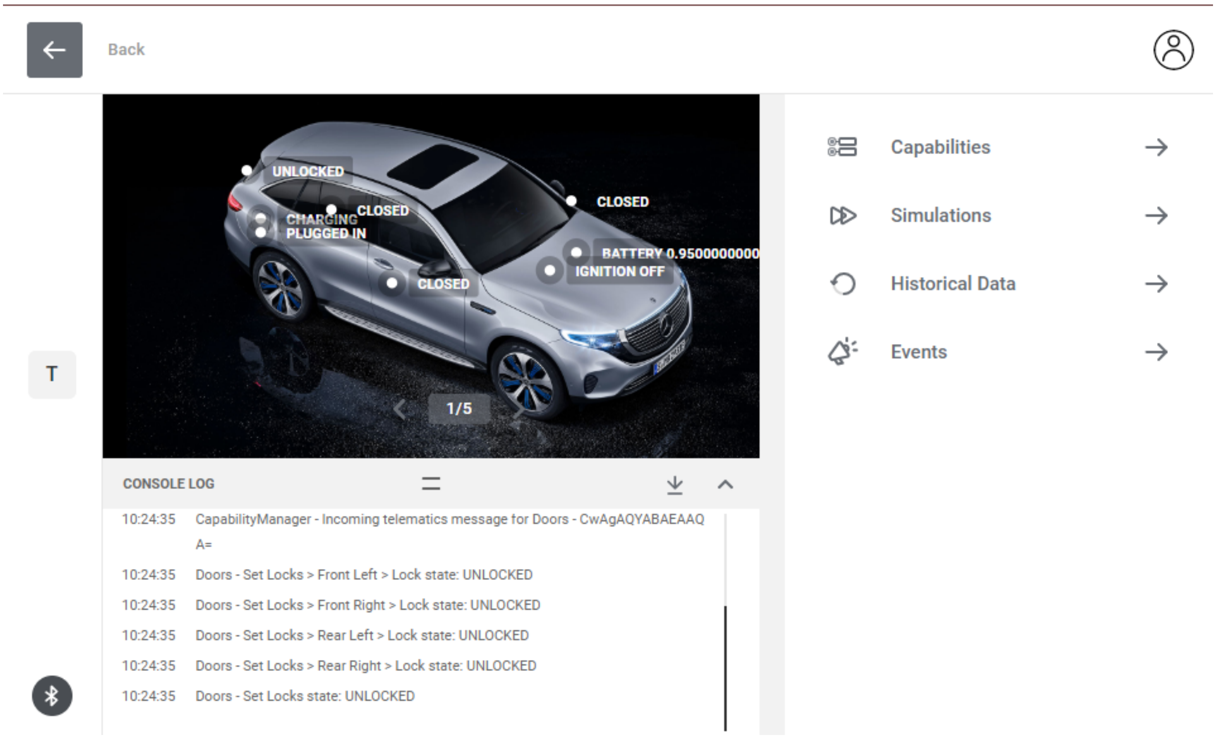

Figure 4.3: High Mobility vehicle emulator with console log, Source: [26]

The emulator operates within the browser and is available on the platform where the application's setup takes place. This emulator offers the possibility to simulate different vehicle events, scenarios, and the direct manipulation of various vehicle capabilities like window or door locks. The capabilities of the emulated vehicles and the API commands provide a detailed representation of a real car. But only a fraction of this can be triggered productively due to the restrictions from the OEMs[35].

4.2.4 Mercedes-Benz /developers implementation

The Mercedes-Benz API platform by Daimler does not offer a JavaScript SDKs, but only SDKs for the mobile operating systems Android & iOS[98]. Therefore the REST interface was implemented within the web-application.

The lack of a missing front-end SDK is not a big issue, since the REST interfaces are well documented and structured. Each API is divided into a general overview, a API specification, and further documentation for detailed example snippets. This makes it easy to navigate through the various APIs to the information that is needed.

At first, the OAuth-process by the authorization Code flow as described in table 4.1 needs to be implemented. For this topic, the platform offers a separate documentation[133]. Once the process is implemented the user of the application is able to login onto the Mercedes-Benz platform to authenticate and authorize the application to the platform and the respective emulated vehicle. The provided access-token is then used within the HTTP header for any request by the API call to authorize with the vehicle as seen in the example 4.4:

```
return axios
    .get(
      'https://api.mercedes-benz.com/
        experimental/connectedvehicle/v1/vehicles/7AE774D032F2C5F2A1/doors',
      {
        headers: { Authorization: "Bearer 7eceb640-2e2b-4471-bf23"}
      })
      .then(async (response) => {
        res.send(response.data)
      });
```

Code example 4.4: Mercedes-Benz Connected Vehicle door REST example

In this example the door state via the Connected Vehicle API is queried with the vehicle id '7AE774D032F2C5F2A1' and the access token '7eceb640-2e2b-4471-bf23'.

A simplified response of a door state request can look like this in the code example 4.5. In general, the information is delivered for each individual door.

```
   "doorlockstatusvehicle": {
    "value": "LOCKED",
    "timestamp": 1595364300
    }
```

Code example 4.5: Mercedes-Benz door look response (simplified)

A vehicle emulator that is powered by High Mobility, provides the same functionality and gives direct feedback in the console of each API call[151] as shown in figure 4.4.

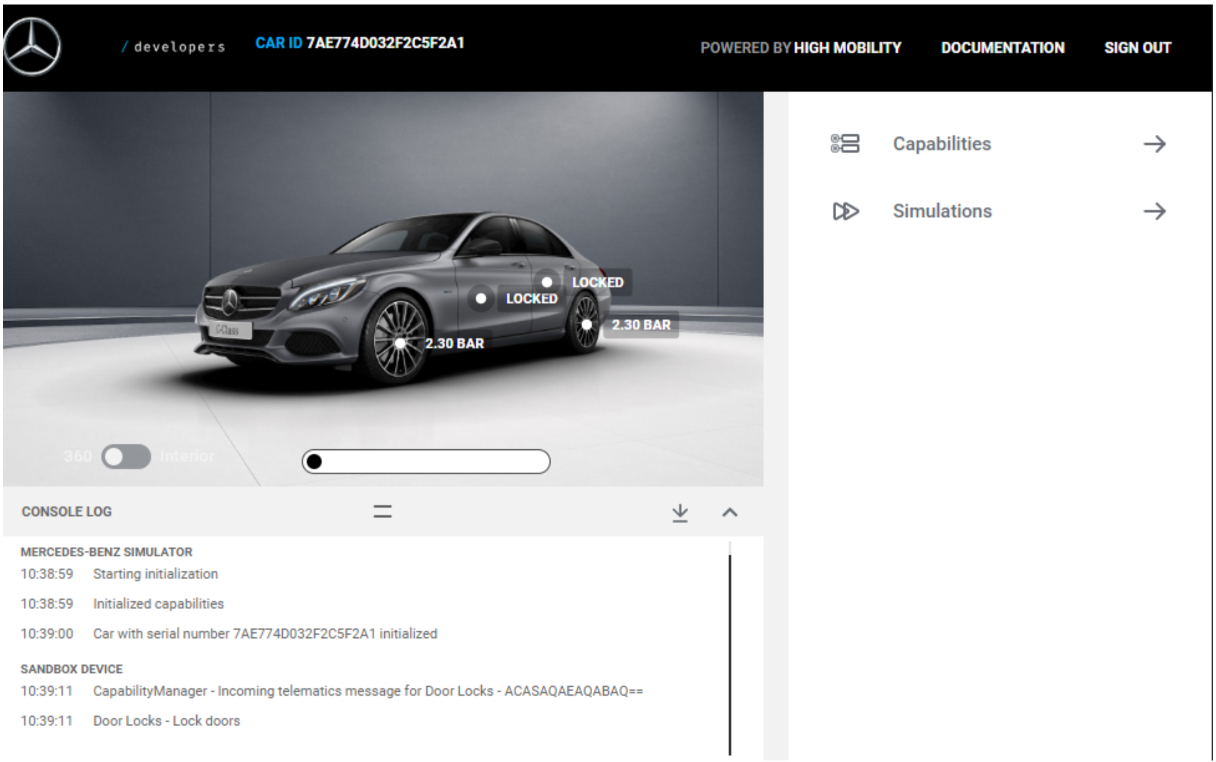

Figure 4.4: Mercedes-Benz vehicle emulator with console log, Source: [151]

4.2.5 Otonomo implementation

Unlike the other API platforms, Otonomo does not offer any SDKs and relies only on REST interfaces[81]. On the "consumer playground", the platform offers a pre-configured personal & aggregate demo service for free. It depends on the desired service which OAuth-flow needs to be implemented. For the aggregated service, the client-credential-flow by the use of ClientID & ClientSecret has to be used, while a personal service is authorized by the authorization-code-flow. In the demo account the personal service is generally not available and can therefore not be tested.

Aggregated service

According to the demo description for the aggregate data service, it is easy to implement by its REST APIs[152]. Otonomo offers a Postman collection for this[8] to test the interfaces before an implementation. However, the collections are not working and seem to be outdated or misconfigured due to the receipt of bad-request responses from the platform while requesting an access token. Nevertheless, this is no concern by the use of the REST implementation according to its API reference[81, 152].

After the access-token is received, reports of the aggregated service can be requested to receive anonymized vehicle data.

The service is identified thought the provided access-token as shown below in 4.6:

```
const start_datetime     = "2019-01-19 00:00:00";
const end_datetime       = "2019-01-20 00:00:00";
// set http specific options and request-related filters in body
var options = {
    'method': 'POST',
    'url':
        'https://api.otonomo.io/v1/aggregate/reports/AnonymousHistoricalRawData/',
    'headers': {
      'Authorization': 'Bearer eysYPTgrnaKhdIkX7Mc8Ivg',
      'Content-Type': ['application/json', 'application/json']
    },
    body: JSON.stringify({
        "start_datetime":start_datetime,
        "end_datetime":end_datetime
        })
};

request(options, function (error, response) {
    res.send(response); // send response to front-end
});
```

Code example 4.6: Otonomo AnonymousHistoricalRawData REST report request example

For demo data, only the pre-configured, non adjustable demo services can be addressed by the APIs. In the beginning, it was unclear that this default demo service needs to be used to request demo data.

The requested aggregate demo service only offers real historical data of January 2019 from vehicles located in the UK[152]. This demo service consists of two reports with a snapshot of static vehicle information and trip summary data for individual vehicle trips at a specified time including vehicle specifics, battery data, fuel consumption, location, speed average, distance, start, and destination. Of course, this is just demonstration data. The real availability of this data may look different.

The example 4.6 above initiates the generation of the "AnonymousHistoricalRawData" report for the period 2019-01-19 – 2019-01-2020.

Unfortunately, the requested data reports are not available on request (asynchronous) and have to be processed by the platform before the information is made available.

The status of reports need to be verified by its given id, received by the generation API call as shown below in example 4.7:

```
const id = res.req.query.request_id // id to be checked
var options = {
    'method': 'GET',
    'url': 'https://api.otonomo.io/v1/aggregate/reports/requests/'+id,
    'headers': {
      'Authorization': 'Bearer eysYPTgrnaKhdIkX7Mc8Ivg',
    }
};

request(options, function (error, response) {
  res.send(response)
});
```

Code example 4.7: Otonomo Request Report Status REST example

Once a report generation is done, the report status changes to 'completed' and delivers the respective download link. A response of a request in example 4.7 of a completed report generation looks like this in 4.8:

```
{"status":"Completed",
 "id":1002339,
 "result_url_list":{
     "part-00000-adc6787a-ef46-4831-93ba-14b7f07abc38-c000.csv":
     {
        "size":38434134,
        "url":"https://prod-otonomo-reports.s3-accelerate.amazonaws.com/
               1002339/part-00000-adc6787a-ef46-4831-93ba-14b7f07abc38-c000.csv"
     }
  },
 "report":"AnonymousHistoricalRawData"
}
```

Code example 4.8: Otonomo Request Report Status REST response example

The data of all provided APIs for aggregated data is only accessible by the additional "Request Report Status" API. The data access of the requested data is provided by its download-unique resource locator (URL) to an comma-separated values (CSV) file once the report status is completed.

A CSV report opened with Excel could look like this in figure 4.5:

	A	B	C	D	E	F	G	H	I	J
1	mobility__speed__average	mobility__speed__maximum	manufacturer__fuel_type__valu	mobility__distance__traveled	location__city__end	location__country__start	location__city__start	location__country__end	mobility__odometer	location__city__summary
2	92.24137931	108	Electric	17.32333027	london	gb	london	gb	64343.4	london
3	78.82352941	100	Electric	18.37100208	london	gb	london	gb	55274.2	london
4	102.6666667	107	Electric	5.070387698	london	gb	london	gb	50455.2	london
5	96.47058824	104	Electric	11.69427989	london	gb	london	gb	28006	london

Figure 4.5: Aggregate CSV example data, Source: [117]

Alternatively, the reports can be generated, reviewed, and downloaded on the consumer playground in the browser.

Personal service

For the personal service implementation, the authorization code OAuth-flow is required to get a driver access-token. This process is also described in Otonomo's tutorial documentation [8], but is not possible with the demo service. For test purposes, the current test environment of Otonomo is not intended to implement a stand-alone OAuth-flow for personal services. Personal vehicle data can only be tested with a manually extracted access-token from the personal service playground that is provided during a running vehicle simulation within the browser. This simulation must be configured on the playground first, which features a moving car that drives a pre-defined route, and a few vehicle scenarios to choose from. But this vehicle cannot be manipulated during the simulation. Once the simulation runs in the browser the access-token can be extracted and used within the test implementation until it is expired. How this playground simulation looks like is shown in the figure 4.6 below.

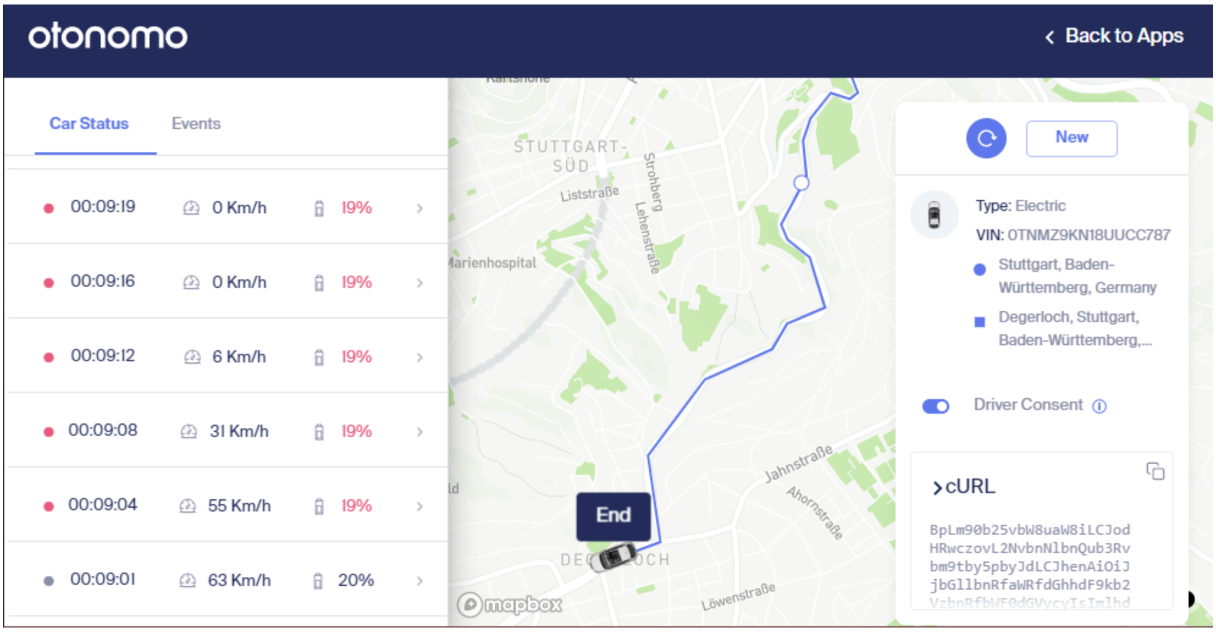

Figure 4.6: Otonomo playground simulation, Source: [117]

The following example 4.9 shows the "Vehicle Status" API. The response contains the requested data in a JSON format and is available on request.

```
//this is extracted from the playground's simulation
const bearer    = 'Bearer eyJhbGciOiJSUzI1NiIsI';
const url       = 'https://market.otonomo.io/cars/v1/status/';

//set options
var options = {
  method: 'GET',
  url: url,
  headers: {authorization: bearer}
};

request(options, function (error, response) {
    // send back the response
    res.send(response)
});
```

Code example 4.9: Otonomo Vehicle Status REST example

A response looks like this in the code example 4.10.

```
"data": {
    "tire_pressure_fl": 32,
    "provider": "otonomo",
    "tire_pressure_rr": 32,
    "state_of_charge": 19.98,
    "fuel_consumption": 8.0,
    "fuel_level": 19.98,
    "time": 1595369355091,
    "tire_pressure_rl": 32,
    "otonomo_id": "d2f0e8f2bc585125b8f5499bc895389e",
    "odometer": 86027.0,
    "speed": 0.0,
    "heading": 184.1,
    "fuel_type": "Electric",
    "oil_level": 100,
    "battery_level": 12,
    "latitude": 48.7713185,
    "tire_pressure_fr": 32,
    "longitude": 9.1870942,
    "steering_wheel_angle_position": 0.0,
    "battery_voltage": 300,
    "vin": "0TNMZ9KN18UUCC787",
    "engine_temp": 89.3
}
```

Code example 4.10: Otonomo Vehicle Status response example (simplified)

Otonomo does not offer a virtual car that can be manipulated to test personal services properly.

In general, the lack of documentation is also a drawback. By the time of the test implementations, the documentation is insufficient compared to the other analyzed platforms. In addition, the documentation often contains dead links. While experimenting and testing the APIs, some details can only be clarified by mail support. For example, the dedicated consent link for personal services from Europe was not included in the API documentation. Unfortunately, this is obsolete in a test implementation in the free price model anyway due to the demo-restrictions for personal services. This was also not obvious from the API description. Since Otonomo does not provide SDKs or examples on GitHub as well as no other public support channels sch as forums, for instance, a test implementation is significantly more difficult.

4.2.6 Smartcar implementation

The Smartcar API is easy to implement in a web application with the use of its Node.js SDK provided by npm or GitHub[153, 154]. Besides that, its online documentation does provide code snippets for all supported programming languages[130].

Following the Node.js tutorial[155] the interface works without the use of any HTTP client. The SDK relieves in the OAuth-flow with its AuthClient like in the example 4.11 below where the necessary permissions are set which the user needs to grant.

```
 const smartcar = require('smartcar');

// Redirect to Smartcar Connect
redirect_uri = 'http://localhost:3000/smartcar-api';

client = new smartcar.AuthClient({
  clientId:     smartcarClientID,
  clientSecret: smartcarClientSecret,
  redirectUri:  redirect_uri,
  scope: [
    'read_odometer', 'read_vehicle_info', 'control_security',
    'read_engine_oil', 'read_battery', 'read_charge', 'read_fuel',
    'read_location', 'read_tires', 'read_vin'
    ],
  testMode: true, // launch Smartcar Connect in test mode
});

const url = client.getAuthUrl();

// redirect to the link
res.send(url);
```

Code example 4.11: Smartcar AuthClient SDK example

Once the authentication is requested and the access-token stored by its callback, the application is ready to query the APIs as follows in the example 4.12.

```
var vehicle;
var returnData = [];

// get the user's vehicles
await smartcar.getVehicleIds(accessToken)
    .then(function(res) {
      // instantiate first vehicle in vehicle list
      vehicle = new smartcar.Vehicle(res.vehicles[0], accessToken);
    });

await vehicle.odometer()
  .then(function(data) {
        res.send(data) // send back the data to the front-end
    });
```

Code example 4.12: Smartcar odometer call SDK example

In this example, the respective vehicle is stored first, while the odometer of this vehicle is queried afterward. Unfortunately, it is not possible to review or manipulate the virtual test vehicle within an emulator.

A response of an odometer request like above looks like this in example 4.13.


```
{
    "data": {
        "distance": 209317.8125
    },
    "age": "2020-07-21T22:21:04.777Z",
    "unitSystem": "metric"
}
```


Code example 4.13: Smartcar odometer call response example

Overview of the implemented interfaces

The implemented APIs of each platform are shown in the overview in table 4.7.

Provider	Personal	Aggregate	Interface name	Implementation	Version	Date
High Mobility	x		Auto API HMKit: downloadAccessCertificate	Node.js SDK	11.1	09-Mar-2020
High Mobility	x		Auto API HMKit: commands.Doors	Node.js SDK	11.1	09-Mar-2020
High Mobility	x		Auto API HMKit: commands.VehicleStatus	Node.js SDK	11.1	09-Mar-2020
Mercedes-Benz	x		OAuth Authentication	REST	1.0	17-Jan-2018
Mercedes-Benz	x		Connected Vehicle[1] /doors	REST	1.0	17-Jan-2018
Mercedes-Benz	x		Connected Vehicle[1] /vehicle	REST	1.0	17-Jan-2018
Otonomo		x	Service Access Token	REST	1.1	Apr-2020
Otonomo		x	Anonymous Historical Raw Data[2]	REST	1.1	Apr-2020
Otonomo		x	Request Report Status	REST	1.1	Apr-2020
Otonomo	x		Vehicle Status[3]	REST	1.1	Apr-2020
Smartcar	x		Smartcar Node SDK / AuthClient	Node.js SDK	7.4	24-Oct-2019
Smartcar	x		Smartcar Node SDK / Vehicle	Node.js SDK	7.4	24-Oct-2019

1 Status: Experimental
2 Only available in demo mode
3 In the demo mode the implementation is only possible by manually extraction of the Auth-token from its development simulation platform

Table 4.7: Implemented APIs overview, Sources: [81, 153, 130, 142, 143, 110]

The implementation of those APIs served as a foundation for the following API design evaluation.

4.2.7 API design evaluation

The API design criteria in table 4.8 represent a selection of categories that ensure proper implementation of programming interfaces based on specifications & guidelines of W3C[156], Microsoft[157] the Richardson Maturity Model[158], the Internet Assigned Numbers Authority (IANA)[159], the Internet Engineering Task Force (IETF)[160] and the OpenAPI specification[161]. As it is available across all analyzed platforms, most criteria are focused on the REST interface. The final evaluation result is shown in section 4.2.8.

API design criteria	Reference	Description
Attribute & method notation	Node.js SDK	Attributes and methods use `pascalCase`, also known as `interCaps`.
Constant notation	Node.js SDK	Constants are written in capital letters
Name space and prefixing	Node.js SDK	Use of methods and attributes that extend existing interfaces e.g. `var toaster = new acme.Toaster();`
Resource-based identification (URIs)	REST	Separate SDK for each identifiable resource e.g. `https://adventure-works.com/orders/1`
Self-explanatory resource set	REST	Structure of URL & URIs are self-explanatory e.g. `http://example.com/user/1234` = user with ID 1234
HTTP status codes	REST	Compliance with the generic HTTP status codes based on IANA.org
HTTP request methods	REST	Use of HTTP methods according to their specification: `GET, POST, PUT, HEAD, DELETE, OPTIONS`
Significance of errors	REST	Informative error description as a server response
Word separation in URLs	REST	Use of hyphens (-) instead of underscores (_), no camel/pascal-case
Naming conventions of resources in URLs	REST	Use of lower case letters, no file extensions in URIs, no verbs, no closing slash (/) & restricted use of plural identifiers
Access to collections	REST	Use of collective identifiers to access collections: e.g. `https://example.com/orders`
HTTP header usage	REST	Use of HTTP headers for metadata, security etc.
Query parameters	REST	Use of query parameters if necessary: Paging, filtering, sorting, searching e.g. `/orders?limit=25&offset=50`
API versioning	REST	Versioning of the API in the HTTP header or directly in the URL
OpenAPI specification availability	REST	Availability & naming of an OpenAPI specification: `openapi.json` or `openapi.yaml`

Table 4.8: API design evaluation design criteria, Sources: [159, 160, 161, 156, 157, 158, 160, 161]

The evaluation of each criteria evaluation follows in the tables 4.9-4.10.

API design criteria	**High Mobility**	**Mercedes-Benz**	**Otonomo**	**Smartcar**
Attribute & method notation	Properly implemented	no Node.js SDK available	no Node.js SDK available	Properly implemented
Constant notation	Properly implemented	no Node.js SDK available	no Node.js SDK available	Properly implemented
Name space and prefixing	Properly implemented	no Node.js SDK available	no Node.js SDK available	Properly implemented
Resource-based identification (URIs)	Properly implemented	Properly implemented	Properly implemented	Properly implemented
Self-explanatory resource set	Properly implemented	Properly implemented	Properly implemented	Properly implemented
HTTP status codes	Error codes are described for each API, status codes properly used - but rarely	Error codes are described for each API, status codes properly used	Error codes are described in general only, status codes are partly improperly used	Error codes are described in general only, status codes widely used but partly differ with specification
HTTP request methods	Use of `PUT`,`GET`: use of `PUT` to execute actions	Use of `GET`,`POST`: `POST` to execute actions	Use of `GET`, `POST`: `POST` to request new report	Use of `GET`,`POST`,`DELETE`: `DELETE` to disconnect, POST to execute actions & subscriptions

Table 4.9: API design evaluation result details 1, Sources: [154, 142, 156, 157, 158, 162, 110, 130, 81, 159, 160, 161, 163, 130, 110, 162, 130, 159, 164]

API design criteria	High Mobility	Mercedes-Benz	Otonomo	Smartcar
Significance of errors	Fault type distinction & individual error descriptions per API	Fault type distinction & individual error descriptions per API	Generalized error descriptions related to HTTP Status codes	Error-Type distinction + Individual error descriptions per API as response
Word separation in URLs	use of underscores	use of `camelCase`	use of `PascalCase` e.g. `.../AnonymousHistoricalRawData/`	Properly implemented e.g. `.../engine/oil`
Naming conventions of resources in URLs	use of verbs like get or set e.g. `activate_deactivate_start_stop`	Properly implemented	Properly implemented	Properly implemented
Access to collections	Properly implemented	Properly implemented	Properly implemented	Properly implemented
HTTP header usage	Properly implemented	Properly implemented	Properly implemented	Properly implemented
Query parameters	Use of URL parameters only for OAuth flow	Use of URL parameters only for OAuth flow	Use of URL parameters only for OAuth flow	Use of URL parameters only for OAuth flow
API versioning	Versioning by the entire API: stock `.../v3/doors`	Versioning by each API: `.../connectedvehicle/v1/doors`	Versioning by the entire API stock: `.../v1/vehicles/...`	Versioning by the entire API stock: `.../v1.0/vehicles/...`
OpenAPI specification availability	Available for the entire API stock	Available for each API separately	n.a.	n.a.

Table 4.10: API design evaluation result details 2, Sources: [162, 130, 163, 110, 157, 158, 81, 162, 110, 130, 81]

4.2.8 API design evaluation result

The API design evaluation results are presented by a point-score in table 4.11 below. An evaluation of each category can obtain the numbers zero (not applied), one (partly applied) or two (properly applied). The respective explanation of each criteria evaluation was explained in the tables 4.9-4.10.

API design criteria	**Reference**	**High Mobility**	**Mercedes-Benz**	**Otonomo**	**Smartcar**
Attributes & methods notation	Node.js SDK	2	n.a.	n.a.	2
Constants notation	Node.js SDK	2	n.a.	n.a.	2
Name space and prefixing	Node.js SDK	2	n.a.	n.a.	2
Resource-based identification (URIs)	REST	2	2	2	2
Self-explanatory resource set	REST	2	2	2	2
HTTP status codes	REST	2	2	2	2
HTTP request methods	REST	1	2	2	2
Significance of errors	REST	2	2	1	2
Word separation in URLs	REST	0	0	0	2
Naming conventions of resources in URLs	REST	1	2	2	2
Access to collections	REST	2	2	2	2
HTTP header for authentication	REST	2	2	2	2
Query parameters	REST	0	0	0	0
API versioning	REST	1	2	1	1
OpenAPI specification availability	REST	2	2	0	0
Average value (higher is better)		1.5	1.7	1.3	1.7
Result		++	+++	+	+++

Evaluation: 0=not applied; 1=partly applied; 2=properly applied

Table 4.11: API design evaluation results

The final result is based on the average value resulting from the individual values of the available categories for each party. The best average value indicates the best result (+++), while the other parties follow this value in a graded manner (+ or ++).

4.2.9 Evaluation summary

Based on the technical realization via the Node.js SDKs of High Mobility and Smartcar the naming of attributes & methods according to pascal-case is implemented consistently[154, 142]. Also, the use of capital letters for constants and extending interfaces follows the regulations[156].

Regarding the REST-interface-defined categories, its fundamental basis of resource-based identification by unique resource identifiers (URIs) was no concern[157, 158]. All APIs use URIs with self-explanatory structure and naming[162, 110, 130, 81].

Status codes

According to the standards of IANA[159, 160, 161], Smartcar and Otonomo partly differ with the specification of HTTP status codes and are described only in general and not tailored for each API[163, 130].

Otonomo uses the codes 401 (unauthorized) & 403 (forbidden) identically in the case of consent lack by the car-owner passed through from the OEM. These codes only need to be used either for authorization or credential issues.

Smartcar uses code 409 (version conflict) for inaccessible vehicles whereas code 408 (request timeout) would be more appropriate. Furthermore, code 430 (unassigned) is used for exceeding the monthly request limit [130]. However, the code 429 (too many requests) would be a better fit[159]. In general, Smartcar widely uses the range of status codes.

Mercedes-Benz and High Mobility properly describe status codes for each API, but High Mobility uses the variety of status codes rarely in comparison. Apart from that, all other status codes such as 200 (OK) are used properly [162, 110].

Error significance

As part of the status code analysis also the significance of error responses was evaluated. High Mobility, Mercedes-Benz & Smartcar categorize different types of faults into different fault types and offer individual error descriptions for each API[162, 130]. Otonomo on the other hand provides only generalized error descriptions related to each HTTP status code which is not a major disadvantage concerning the lesser amount of APIs[163].

Request methods

Regarding the use of HTTP request methods[158] with the APIs, all platforms properly use the GET method to receive vehicle data. For remote control, Mercedes-Benz and Smartcar use the POST method to execute car actions whereas High Mobility uses the PUT method[110, 162, 130]. Based on the IANA specification[159], the PUT method is used to update resources while POST stands for the creation of new resources. However, there is no definition of which method is more appropriate to realize vehicle remote control. The technical difference that must be considered is the idempotent character of PUT, which means that repeated requests give the same response, while POST delivers a deviant response if a request has already been executed[164]. Otonomo does technically not support remote control for their personal services[81] but uses POST to request new reports for automotive mass data. Smartcar is the only provider that makes use of the DELETE method to disconnect vehicles from the platform.

Naming, versioning & documentation

To improve readability in URLs, Microsoft recommends[157] to use hyphens (-) instead of underscores (_) and pascal/camel-case for word separation[157]. High Mobility uses underscores, whereas Mercedes-Benz uses camel-case and Otonomo pascal-case. In contrast, Smartcar avoids the use of word separation through its structural organization by using individual URIs.

According to naming conventions the use of lower case letters, nouns, and singular need to be preferred[157, 158]. Closing dashes and file extension must be avoided in REST URLs. This is followed by all parties except for High Mobility which uses verbs for their endpoints[162].

The access of collections by collective identifiers and the HTTP header-based authentication is implemented properly by each[157, 158].

In the case of URL query parameters[157, 158], no use is made besides the authentication flow on every discussed platform. Also the realization of the API versioning offers hardly any differences. Each platform implements the version within the URL endpoint[162, 110, 130, 81]. However, Mercedes-Benz is able to version each API individually via its differently structured URLs instead of version the entire API stock by its base URL.

Also in terms of documentation via the OpenAPI specification[161], Mercedes-Benz offers descriptions for each API[110]. High Mobility offers this for the entire API stock whereas Otonomo and Smartcar do not provide any OpenAPI specification[162, 110, 130, 81].

4.2.10 Evaluation conclusion

In general the API platforms follow the examined rules and guidelines described in the tables 4.9-4.10. Noticeable differences exist in the guidelines according to HTTP methods, error handling, resource naming conventions, and the general documentation of the interfaces.

Otonomo needs improvement in terms of API documentation and error significance to deliver more, tailored information in the case of incorrect API implementation or wrong configurations as it was hard to identify sources of error. But the most noticeable is the lack of proper URI word-separation and the missing state-of-the-art documentation of the interfaces via the OpenAPI specification.

Smartcar and Mercedes-Benz do a great job in following the most common API design rules and differ only in detail. While Mercedes-Benz is not as accurate as Smartcar in terms of word-separation, the platform stands out through its refined APIs versioning which is a benefit for the platform provider itself.

High Mobility is hardly less strict than the leading competitors in this comparison. Only in the HTTP method for remote control and the use of underscores regarding word division in their REST URLs differ.

None of the parties use query parameters in their REST-APIs which can be useful to filter or restrict data directly in the API call for fleet or other mass data. Other than that it can be an alternative to individual resources in the URL.

4.3 Overall comparison

The introduced connected car API platforms differ in their product portfolios. Smartcar offers a similar service to High Mobility and focuses on personal connected car services, but is less partnership-oriented, as there is no reference to the ExVe concept or the principle of the neutral server. The platforms of High Mobility, Mercedes-Benz & Otonomo are accessible for B2B use only. However, Daimler has started becoming more open and developer-friendly with its BYOCAR tier. Whereas High Mobility and Smartcar focus on personalized vehicle data across various car brands, Otonomo on the other hand is positioned differently with its automotive mass data and appeals to much greater institutions as target groups. Nevertheless, the platform in general is not mature yet due to unavailable creation and testing of personal services as well as the streaming interfaces.

What all providers have in common is a free development and test environment to experiment and encourage new connected car services. However, the vehicle emulator of High Mobility and Mercedes-Benz shows its benefits with direct API feedback and real-life capability and scenario setups. The scenario simulator of Otonomo is less extensive and does not offer as much support in development.

4.3.1 Transparency and subjective opinion

All platforms offer information on which attributes are available for which vehicles in production. For personal services, High Mobility and Otonomo offer guides or datasheets for the respective supported OEMs which clarify the use and availability of the data.[59, 60, 97, 96]. This barely differs between the platforms and the OEMs. In this respect, this concludes that the release of data is tailored by the OEMs and is not adjusted for the individual platforms. Smartcar also provides information about the individual OEM compatibility[165] but detailed compatibility information is reserved for the chargeable price models. The proprietary platform by Daimler delivers this information for each model and date of production in detail for free. However, currently, it is still unclear which use-cases are widely applicable. According to the datasheets of the neutral servers[59, 60, 97, 96], it is obvious that the compatibility depends on the manufacturer and the model. An overview of the real-life available attributes is shown in appendix A. Which attributes are actually available for which model in particular is not guaranteed, yet.

As far as the general perception of information transparency is concerned, the platforms of Daimler, High Mobility, and Smartcar are very open. However, with the open-source approach and various support channels for developers, High Mobility is committed to full transparency. Otonomo, on the other hand, does not make a good impression due to the comparatively low quality of API documentation and the missing references regarding real-life showcases and how the Consent Management Hub operates in practice. Besides BMW and Mercedes-Benz, there is no information about which other vehicle brands are supported for personal services and which data providers are involved in the platform to fulfill aggregated services. In this respect, mail inquiries were either not or cautiously answered (as seen in appendix B).

Since Smartcar is not supposed to rely on official partnerships but rather access the interfaces independently, it has the advantage of supporting the largest number of vehicles for personal services. However, there is no indication of how reliable this approach works in practice and what the response among third-party providers is in this respect. Nevertheless, they are probably leading in terms of the abstraction of a large number of manufacturer interfaces.

4.3.2 Comparison overview

A summary how each connected car API platform performs, is shown in the following. The comparison is divided into the business (table 4.13 & 4.14) and technical part (table 4.16 & 4.17). The tables 4.12 & 4.15 give an explanation for each comparison category.

Business category	**Explanation**
Aggregate data service	Collected anonymized vehicle mass data
Availability of vehicle data	Platforms information in intervals the vehicle data is available or updated by the vehicles.
Batch requests	Request several APIs at once with one request (either via REST or SDK)
Data Sources & countries of operation	Where does the data come from and area of operation
Freemium price model or free trial	Limited live services are provided free of charge
In-Vehicle data vehicle access	Remote short-range vehicle access via Bluetooth
Location & Data sovereignty	Provider's country of origin
Official ISO 20077/20078 compliance	Implementation of the neutral server principle according to ISO 20077, 20078
Official ISO 20080 compliance	Remote diagnostic data access according to ISO 20080
Official product references	Publicly known productive showcases, customer references
On-demand pricing	Billing only for the actual number of connected car or API calls
Patented technology	Protected methods for providing aggregated data services
Personal data access	Remote access to personal vehicles data with user consent
Personal service compatibility	Supported OEMs & data sources in live mode for personal services
Personal service remote control	Support of remote control of personal vehicles with user consent e.g. lock doors
Startup program	Tailored conditions for small businesses
Streaming / webhooks	Automatic reception of data at pre-configured intervals or conditions

Table 4.12: Connected car API platforms comparison business categories

Business category	**High Mobility**	**Mercedes-Benz**	**Otonomo**	**Smartcar**
Aggregate data service	☐	⧆[3]	☑	☐
Availability of vehicle data	Depends on OEM: Immediate data update with the latest data available on the OEM servers	Response with the latest data available on the servers	near real-time	no information
Batch requests	⧆[2]	☐	☐	☑
Data sources & countries of operation	European Economic Area (EEA) & CH	European Economic Area (EEA) & CH	112 countries worldwide	Mainly USA
Freemium price model or free trial	☐	⧆[1]	☑	☑
In-Vehicle data vehicle access	☑	☐	☐	☐
Location & data sovereignty	Germany/Europe	Germany/Europe	Israel/Middle East	California/USA

☐- not available; ⧆-limited/non - productive availability; ☑- available or fulfilled

[1] With BYOCAR only for testing purposes (limited access)

[2] Only for mobile Android SDK

[3] Not publicly available

Table 4.13: Connected Car API platforms business comparison 1, Sources: [26, 60, 59, 103, 106, 100, 110, 65, 61, 7, 125, 81, 87, 88, 63, 62]

Business category	**High Mobility**	**Mercedes-Benz**	**Otonomo**	**Smartcar**
Official ISO 20077/20078 compliance	☑	☑	☑	☐
Official ISO 20080 compliance	☐	☑	☐	☐
Official product references	☑	☑	☐	☑
On-demand pricing	☑	☑	⧆[2]	☐
Patented technology	☐	☐	☑	☐
Personal data access	☑	☑	☑	☑
Personal service compatibility	3 (private vehicles: Mercedes-Benz, BMW, MINI)	Proprietary commercial (MY>'18) & private vehicles (MY>'16/'17)	3+ (private vehicles: Mercedes-Benz, BMW, MINI,+)	19[*]
Personal service remote control	⧆[1]	☑	☐	☑
Startup program	☑	☑	☐	☑
Streaming / Webhooks	☑	☐	☑	☑

☐- not available; ⧆-limited/non - productive availability; ☑- available or fulfilled

[1] not in production yet, due to OEM restrictions

[2] pay-per-use only for aggregated services

[*] Audi, BMW, Buick, Cadillac, Chevrolet, Chrysler, Dodge, Ford, GMC, Jaguar*, Jeep, Land Rover*, Lexus, Lincoln, Nissan, Ram Trucks, Tesla*, and Volkswagen (*Europa)

Table 4.14: Connected Car API platforms business comparison 2, Sources: [38, 99, 106, 26, 162, 110, 65, 98, 116, 120, 87, 88, 63, 62, 130, 85]

Technical category	Explanation
Assistance for implementation I	API documentation with example code snippets
Assistance for implementation II	Proper documentation of REST APIs using the OpenAPI specification
Assistance for implementation III	Availability of Tutorials, Postman collections and example apps
Active Community	Active participation and establishment of an own community by forums, GitHub or online-publishing-platforms
Application's rate limits	Restrictions on API calls in production mode
Available SDKs back-end	Software Development Kits for back-end applications
Available SDKs for mobile	Software Development Kits for mobile operating systems iOS & Android
Available SDKs front-end	Software Development Kits for front-end applications
Free customer support	Free of charge technical implementation support
General test environment	APIs can be tested and evaluated with test data
Open-source SDKs	Transparent implementation with open-source libraries
Private offer for individual developers	Services are also offered to individual developers and not only for B2B
Quality API Design	Proper technically interface design based on guidelines & specifications
Short-time go live process	Switch test application into production mode within one day
Visual Car emulator	Applications can be tested directly in the web browser with an emulated vehicle representation for personal vehicle services

Table 4.15: Connected car API platforms comparison technical categories

Technical category	**High Mobility**	**Mercedes-Benz**	**Otonomo**	**Smartcar**
Active Community	Blog, Forum, GitHub, Slack	GitHub	Blog	Blog, GitHub
Application's rate limits	Depends on the API & OEM: min/hour/car/day-wise	Depends on API: 1 call/VIN per hour - 50 calls/VIN per day	Depends on API: 80 calls per day - 20000 calls per hour/per service	<10 calls / minute & <20 calls per vehicle / hour
Assistance for implementation I	☑	☑	☑	☑
Assistance for implementation II	☑	☑	☐	☐
Assistance for implementation III	Postman collections, Samples, Tutorials	Samples, Tutorials	Postman collections, Tutorials	Samples, Tutorials
Available SDKs back-end	Java, Node.js, Python, Ruby	☐	☐	Go, Java, Node.js, Python, Ruby
Available SDKs for mobile	Android, iOS	Android, iOS	☐	Android, iOS
Available SDKs front-end	☐	☐	☐	JavaScript/React
Free customer support	☑	☑	☑	⧆[1]
General test environment	☑	☑	☑	☑

☐- not available; ⧆-limited/non - productive availability; ☑- available or fulfilled

[1] Restricted in response time

Table 4.16: Connected Car API platforms technical comparison 1, Sources: [10, 166, 167, 76, 128, 162, 110, 81, 130, 98, 162, 168, 142, 154]

Technical category	High Mobility	Mercedes-Benz	Otonomo	Smartcar
Open-source	☑	☐	☐	☐
Private offer for individual developers	☐	⧆[2]	☐	☑
Quality API Design[1]	++	+++	+	++
Short-time go live process	☑	☐	☐	☑
Visual Car emulator	☑	☑	⧆	☐

☐- not available; ⧆-limited/non - productive availability; ☑- available or fulfilled

[1] Based on API design evaluation result in 4.2.8

[2] With BYOCAR only for testing purposes (limited access)

Table 4.17: Connected Car API platforms technical comparison 2, Sources: [76, 108, 77, 104, 151, 117, 87]

4.4 Further considerations

According to High Mobility[35], the use-cases of connected car data would be much more diverse if OEMs made more data available regarding the demand of car-sharing and car-rental services as well as other service providers to address vehicles of different brands without proprietary hardware. The car-rental company Sixt, for example, cannot rely on telematics data only due to limited data access and must continue using proprietary hardware solutions for their needs[35]. Car rental companies require data from GPS, maintenance status at certain intervals, but some OEMs are not able or willing to provide this data. There is also a high demand from companies that want to evaluate battery data from electric vehicles to analyze their health status but are also not able to do so yet. Mercedes-Benz has also reported[33] a high demand for fleet management and Car2X-related data through connected car APIs, as this integration and access to the data via APIs is much easier to implement and therefore more cost-effective than proprietary hardware. The cross-manufacturer platforms are prepared for the requirements of the next years with hundreds of possible attributes[169, 162] to implement more data points and write access for remote control. The more OEMs collaborate with these platforms, the more benefits customers will have with the integration, as the effort is less than implementing the APIs of the manufacturers individually.

4.4.1 Manufacturers position on connected car API platforms

In general, OEMs can see which data is requested, relevant, and valuable on their platforms to analyze customer needs and develop new use-cases. According to High Mobility[35], the willingness of OEMs to act jointly with cross-manufacturer platforms varies from OEM to OEM. Some OEMs are not easily accessible to ignite their interest in potential partnerships. However, in comparison, it is remarkable that BMW is more open to share data than Mercedes-Benz and also shares location data of their vehicles, for instance[97, 96]. In the case of JLR[27], for example, vehicle data via APIs are currently not considered as products or as an additional sales channel.

Concerning customer requirements (changes or feature requests), proprietary platforms can react faster in response to customer feedback[33, 35] since data products are provided directly at the source. Providers such as High Mobility and Otonomo, on the other hand, may have to pass on requirements to OEMs first. This again shows the dependence of the platforms on the OEMs.

For OEMs, it is generally irrelevant whether data is accessed via a partner or directly via their own platform - the third-party provider decides which platform is best suited for its purpose. Daimler, for instance, does not see competition from cross-manufacturer platforms since they earn money in both cases[33]. But there is no direct feedback from the community when customers access data via the partners. High Mobility assumes[35] that in the future the platforms will distinguish from each other based on the OEM partnerships and will also stand out through their user-friendliness, accessibility, and transparency to provide third-parties & developers with easy access to the data.

4.4.2 Bearing of costs

Depending on the application a connected car API platform can result in cost savings through process simplification, e.g. for insurance companies to settle a claim. Thus, the costs which arise from the use of connected car API platforms are not borne by the car owner, but are part of the refinancing of the cost savings or are borne by the data consumer himself[35]. In the case of other personal connected car services such as on-demand fueling, the costs are borne by the third-party provider through advertising or are integrated into the price model of the service.

In general, this can also be compared to video streaming services: as soon as people have an advantage or a relief in their everyday life and the price is reasonable, customers are willing to spend money on it. It is also comparable with OEM connectivity car services such as theft alerts via smartphone or logbook exports that save time and provide security. The advantage of these services is that they are already priced in during the development of a vehicle[27]. For OEMs such as JLR, the development of an API platform to provide data products would involve an effort that must pay off first. But the business models currently do not yet justify the integration effort. Currently, it is a niche market, as this is associated with many risks and concerns, says JLR[27].

4.4.3 Risks to be considered

The release of data from OEMs to connected vehicle platforms can also involve risks that are relevant for vehicle owners as well as for the manufacturers themselves. For example, third-parties could create automated data analyses and thereby determine characteristics in terms of the quality of different brands, models, years of manufacture, and regions, which could potentially damage the reputation of the OEMs[27]. Another scenario could be a thief using aggregated data to determine where vehicles of a certain brand or model are, in order to steal specific car components. Furthermore, conclusions can be drawn about a person, for example, if someone did not follow the traffic rules or where someone was going. However, the OEMs and the platforms do everything possible to prevent such conclusions from being drawn via anonymization procedures[119].

5 Conclusion

This chapter summarizes the topics of this thesis and gives an outlook on how connected car API platforms could develop in the future.

5.1 Summary

The objective of this paper was to identify if cross-manufacturer and proprietary connected car API platforms are applicable in practice and how they can be distinguished from each other in business and technical level based on an evaluation & comparison scheme. This was supposed to be the basis for a statement, which platform is better suited for which use-case. The platforms were selected considering that the connected car data is supplied via embedded telematics without additional OBD-II hardware. Moreover, the platform needs to provide a publicly accessible test and development environment. Thus, the choice fell on connected car API platforms High Mobility, Otonomo & Smartcar. Concerning proprietary platforms, the choice was limited. So the only proprietary platform offering a similar portfolio compared to the cross-manufacturer platforms was considered, the "/developers" API platform by Daimler.

Starting with the basics of a connected vehicle, chapter 2 provided an overview of which potential sources a vehicle can deliver, and which data interfaces are common to exchange these data. It turned out that the OBD-II interface should not be used for connected car services due to safety risks. Furthermore, it will be restricted by OEMs for original diagnostic purposes only, as new vehicles have telematics built-in anyway to exchange vehicle data due to regulations such as the eCall. Regarding the use of vehicle data, connected car services, which are hesitantly offered by OEMs, offer much greater potential. Customers are more willing to consume Connected Car Services than offered on the market. By establishing neutral servers via cross-manufacturer connected car API platforms, the supply of connected car services is not only a matter for manufacturers. As a result, third-party services are gradually gaining ground in the development of connected car services via embedded telematics. There is no legal obligation, only commitments for manufacturers to provide vehicle data and various technical attempts to do this consistently across multiple OEMs. But the use of international standards, which are still in development, seems to be growing hand in hand with the evolvement of connected car API platforms. Especially organizations like the European Automobile Manufacturers' Association (ACEA) push making automotive data available to third-party service providers independently. However, the legal obligations regarding data & privacy security compromise this process, and the willingness to release vehicle data for third-parties and its scope differs between OEMs.

To see what kind of impact this has on the platforms, the selected connected car API platforms were roughly introduced in Chapter 3, followed by a description of the data provided by the vehicles. It turns out that the time at which the vehicles send and update their data can vary even between the models of a single manufacturer and can occur event-related or scheduled.

The business and technical analysis in Chapter 4 answered the research questions of how the platforms differ in their business model, functionality, and usability from a third-party implementation point of view. For the technical analysis, a prototypical implementation of each introduced platform was integrated into a web application to evaluate the convenience and design of the interfaces. As a result, a tabular overview was set up to summarize the business and technical criteria separately.

5.2 Overall conclusion

The analysis showed that the market of connected car services and the connected car API platforms is further ahead than the vehicle manufacturers themselves: customers are willing to share data if they benefit by a service or an application. Up to 94 percent of connected car services customers in the USA and 77 percent in Europe show interest in connected car services. Connected car API platforms can already process a lot more information than manufacturers currently provide. Although some manufacturers are open to share their data, they are very cautious about which data is released as this is not reversible. To prevent the misuse of vehicle data and making the approval processes of third-parties easier, the data is bound to fixed use-cases tailored by the OEMs, whether this is a proprietary platform or a neutral server like High Mobility or Otonomo. This increases vehicle security and data protection but slows down the process of getting access to more vehicle data and functions. Technically, the supply of more vehicle data is no concern on the side of the connected car API platforms.

The results of the analysis provide a clear statement regarding the first research question, if cross-manufacturer connected car API platforms are feasible. Both, proprietary as well as cross-manufacturer platforms are usable for real-world implementation if the current, still limited scope of data and functionality does not restrict the use-case. What all providers have in common is a free development and test environment to experiment and encourage new connected car services. But cross-manufacturer platforms offer the advantage that a data protection-compliant vehicle communication only has to be implemented once and can be used across multiple car brands without individual contractual negotiations. In terms of their diversity, the platforms differ in their product portfolios, compatible manufacturers, and their appearance on the market. High Mobility and Smartcar appear to offer a similar service with their focus on personal connected car services. However, Smartcar is less partnership-oriented, as there is no reference to the ExVe concept or the principle of the neutral server. Both High Mobility and Otonomo officially operate as neutral servers for the car brands BMW, Mercedes-Benz, and MINI. Nevertheless, in comparison, Otonomo is differently positioned with its offer of aggregated data and appeals to much greater institutions as target groups. But, the platform in general is not mature yet due to the missing ability to create & test personal services as well as the developing streaming interfaces. Otonomo is the biggest player in this comparison and has grown quicker than its competitors, regarding the number of partnerships and the amount of data the platform is processing. Proprietary platforms are also able to provide aggregated data at first-hand as the supply of this data has more potential in monetization than personal data. Current use-cases for this are already more common, e.g. real-time traffic or parking information whereas use-cases for personal vehicle services like on-demand fueling or usage-based insurance are not popular yet.

The technical evaluation based on individual implementations, guidelines, and pre-defined criteria showed that the platforms barely differ in API design. However, Otonomo needs improvement to provide more tailored error information and state-of-the-art APIdocumentation as well as proper implementation of some API guidelines. Furthermore, the way how aggregated data is provided asynchronously via a CSV file is rather unusual. Moreover, the test implementations showed that there are differences due to the availability of SDKs to support a developer for easier integration. High Mobility and Smartcar made the implementation easier by a wide range of available SDKs, while Otonomo and Daimler only rely on REST interfaces, which require more effort.

The answer to the final question, in which use-cases cross-manufacturer platforms are better suitable compared to proprietary platforms depends on the use-case. Regardless of whether the use of vehicle data is a personal or aggregated service, cross-manufacturer connected car API platforms are better suited when vehicles from several manufacturers need to be addressed. This eliminates the need for contractual negotiations with the individual manufacturers and the implementation of various APIs and authorization processes at minimal extra costs. However, due to missing legal obligations, the manufacturers can reserve data products for themselves, as Daimler does currently, which offers vehicle remote control only with its mobile SDKs, for instance. In general, new data products are more likely to be available sooner on a proprietary platform. Moreover, it can react faster on customer requirements. The individual OEM integration can be an alternative for data consumers with a homogeneous fleet. In the case of aggregated data, it remains to be seen what kind of additional value the cross-manufacturer platforms will offer in the future compared to the proprietary ones. Currently, Otonomo forwards the data without enriching it with any real added value or interpretation as this is left to the third-parties as data consumers. But in terms of data supply, Otonomo also offers data access via its consumer playground using a user interface within the browser. Thus, not only developers but also data analysts who are interested in the history of traffic data can access the data, for instance.

5.3 Outlook

The demand for vehicle data could develop in favor of cross-manufacturer platforms, as this enables more data to become available with one interface. In this context, the integration of new vehicle classes such as light and heavy commercial vehicles and motorcycles could increase the amount of data even further. Besides that, it might be interesting to see how new categories of data and new ways of gathering data through new data channels via external cloud systems would emerge. The data might be delivered directly from the vehicle via Android Automotive, as an example. Moreover, other use-cases would be available through write access to open or close, start and stop vehicles to enable trunk delivery, car-rental/car-sharing, or workshop services that allow maintenance data to be updated without a physical data connection to the vehicle. From time to time, hesitant OEMs could realize that these platforms are more likely to be a multiplier of their revenue from vehicle data than a competitor, as they would still make money by providing access to their vehicles. For example, workshops today buy tools to read diagnostic data. In the future, this could be a bundle of APIrequests per month.

Some data-consumers are likely to remain on data of one or two manufacturers by using proprietary platforms. Also, several use-cases or target groups might only be targeted by the OEMs themselves. Therefore, the cross-manufacturer connected car API platforms and proprietary platforms will certainly have a coexistence.

The demand for access to cross-manufacturer vehicle data might grow faster than what can be offered from these platforms today due to restrictions. But it is a commonly known fact that the data release of OEMs is still limited. Therefore, the growth in customers is moderate. However, this might change with the further integration of additional OEMs and data sources. The potential is not yet really recognized by the market, but in the long run, the connected car API platforms could replace the OBD-II solutions as they might become more profitable on a larger scale.

Overall, when considering the potential industries, it is uncertain if there is already enough data being shared, e.g. for media research purposes, to be valuable for third-parties. Regarding personal services, it is questionable whether the use of the services brings substantial real benefit to a vehicle owner. This could be an indicator of why some industrial sectors are still hesitating to use vehicle data. For these sectors, market research and convincing may still be required to justify these services on the basis of a connected car API platform. Furthermore, it must be evaluated how implementations perform under real-life conditions with real-life vehicles and how the compatibility of attributes looks like.

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Appendix

A Available data via neutral servers

For reasons of clarity, Mercedes-Benz is abbreviated as "MB".

Use-case	Attribute	Description	BMW[1]	MB
General attributes	VIN	Vehicle Identification Number	☑	☑
	Timestamp	Epoch time in UTC	☑	☑
PAYD	Odometer	Accumulated mileage	☑	☑
Fuel Status	Fuel level	Current fuel level in liters or gallons	☑	☑
	Remaining distance	Remaining distance in kilometers or mile	☑	☑
Vehicle Lock Status	Door lock status	The vehicle's doors status	☑	☑
	Deck lid status	The trunk lid status	☑	☑
	Hood State	The vehicle's hood state	☑	☐
	Gas lock status	Locked or unlocked	☐	☑
	Vehicle heading position	The orientation of the vehicle	☑	☑
Vehicle Status (part I)	Door lock status	The vehicle's doors status	☑	☑
	Ignition State	Ignition on or off state	☑	☑
	Window Status	The window status (open/closed)	☑	☑
	Sunroof Status/Convertible Top Status	Sunroof (if the vehicle has one) open/tilt/position state	☑	☑
	Interior Lights Status	Vehicle light on or off status	☑	☑
	Light switch position	On/off, running lights or headlights	☐	☑
	Deck Lid Status	The boot lid status	☑	☑
	Air Temperature	The environmental temperature in Celsius or Fahrenheit	☑	☐

[1] including vehicles of the MINI brand

Table A.1: Available data of Mercedes-Benz & BMW/MINI vehicles via neutral servers 1, Sources: [97, 96, 59, 60]

Use-case	Attribute	Description	BMW[1]	MB
Vehicle Status (part II)	Altitude	The height of the vehicle above sea level	☑	☐
	Battery Voltage	The current battery voltage in the vehicle's electrical system	☑	☐
	Brake Fluid Replacement Date	Date of brake fluid change	☑	☐
	CBS (Condition-Based Service) Count	The maximum number of service notifications transmitted from the vehicle	☑	☐
	AC Charging Voltage	The charging voltage for the most recent charging process	☑	☐
	Charging Method	Describes whether the vehicle was charged with direct current (DC) or alternating current (AC) and which charging plug was used for this purpose	☑	☐
	Charging Profile	The charging profile provides information about the charging mode most recently selected for the vehicle	☑	☐
	Charging Status	The current charging status of the vehicle	☑	☐
	Charging Window Selection	A pre-defined time window in which the high-voltage battery of the vehicle should be charged	☑	☐
	Check Control Messages	Checks control monitor functions in the vehicle and notifies the user when there is a fault in the monitored system.	☑	☐
	Time Threshold for Main and Exhaust Gas Inspection	How many months before the main and exhaust gas inspection is due	☑	☐
	CBS (Condition-Based Services)	Sensors and special algorithms take into account the operating conditions of the vehicle.	☑	☐
	Convertible Roof State	The current status of the convertible roof	☑	☐
	Coolant Temperature	The current coolant temperature in Celsius or Fahrenheit	☑	☐
	Display Unit	The units (kilometers or miles) in which distances are indicated on the vehicle instrument panel	☑	☐
	Driver Front Door	This value indicates whether the front left door was closed	☑	☐

[1] including vehicles of the MINI brand

Table A.2: Available data of Mercedes-Benz & BMW/MINI vehicles via neutral servers 2, Sources: [97, 96, 59, 60]

Use-case	Attribute	Description	BMW[1]	MB
Vehicle Status (part III)	Driver Rear Door	This value indicates whether the rear left door was closed	☑	☐
	Door Lock State	The vehicle's doors status	☑	☐
	Passenger Front Door	Front right door status	☑	☐
	Passenger Rear Door	Rear right door status	☑	☐
	GPS Latitude	The vehicle's degree of latitude	☑	☐
	GPS Longitude	The vehicle's degree of longitude	☑	☐
	Heading	The orientation of the vehicle in degrees	☑	☐
	Hood State	The vehicle's hood state	☑	☐
	Plug Connected	The vehicle connection to a charging plug	☑	☐
	Remaining Fuel Range	The current fuel level range in kilometers or miles	☑	☐
	Legal Inspection Date	Date the next inspection is due	☑	☐
	Number of Free points of interests (POIs)	How many POIs (points of interest) are still open in the navigation system	☑	☐
	Maximum Number of POIs	How many POIs (points of interest) can be stored in the navigation system	☑	☐
	Mileage	The current mileage	☑	☐
	Navigation Arrival Time	The arrival time at the navigation destination in hours and minutes	☑	☐
	Navigation Coordinates	The coordinates of the active navigation destination in milliseconds	☑	☐
	Navigation Distance to Destination	Distance to the active navigation destination in kilometers or miles	☑	☐
	Navigation Remaining Range	The remaining range of fuel in kilometers or miles	☑	☐
	Next Service Date	When the next service is due	☑	☐
	Next Service	How many kilometers or miles remain before the next service at the time of recording the data	☑	☐
	RCP Charging	The charging profile of the vehicle that was configured via the app (remote)	☑	☐
	Remaining Fuel	The fuel tank level in liters or gallons	☑	☐

[1] including vehicles of the MINI brand

Table A.3: Available data of Mercedes-Benz & BMW/MINI vehicles via neutral servers 3, Sources: [97, 96, 59, 60]

Use-case	Attribute	Description	BMW[1]	MB
Vehicle Status (part IV)	Remote Service Result	Informs whether the most recently selected remote service has been executed	☑	☐
	Remote Service Type	This value indicates the most recent remote service type selected	☑	☐
	Charging Status of High-Voltage Battery	The current charging status of the vehicle	☑	☐
	Mileage Data Statistics	The current mileage This value is redundant and is only determined when the regular mileage is not available on the speedometer.	☑	☐
	Teleservice Status	Indicates whether teleservices are available for this vehicle	☑	☐
	Sunroof Position	The current position of the sunroof (if the vehicle has one) in centimeters or inches	☑	☐
	Sunroof State	Sunroof (if the vehicle has one) open state	☑	☐
	Sunroof Tilt State	Sunroof (if the vehicle has one) tilt status	☑	☐
	Trunk State	The boot lid status	☑	☐
	Vehicle Doors Status	The status of the doors is only sporadically recorded and transmitted	☑	☐
	Vehicle Doors	All doors and trunk state	☑	☐
	Engine On Status	Engine on or off state or whether the status is unknown	☑	☐
	Ignition Status	Ignition on or off state or whether the status is unknown	☑	☐
	Light Status	Vehicle light on or off status or whether the status is unknown	☑	☐
	Low Voltage Battery	Current charging status in percentage of the low-voltage battery	☑	☐
	Mobile Phone Connected	Mobile phone is linked to the vehicle or the connection status is unknown	☑	☐
	Motion Status	Vehicle in motion status	☑	☐
	Vehicle Date Time	The time shown in the vehicle at the time of recording the data	☑	☐
	Driver Front Window	The front left window status	☑	☐
	Driver Rear Window	The rear left window status	☑	☐

[1] including vehicles of the MINI brand

Table A.4: Available data of Mercedes-Benz & BMW/MINI vehicles via neutral servers 4, Sources: [97, 96, 59, 60]

Use-case	Attribute	Description	BMW[1]	MB
Vehicle Status (part V)	Passenger Front Window	The front right window status	☑	☐
	Passenger Rear Window	The rear right window status	☑	☐
	First Service Distance	The first time the customer receives a mileage-related message (in kilometers or miles) that the vehicle will soon be due for service	☑	☐
	First Service Time	The first time the customer receives a message that the vehicle will soon be due for service	☑	☐
Vehicle Status: Usage-Based Vehicle Data[2]	Average Distance per Week (long-life)	The average volume of the distance travelled in kilometers or miles per week	☑	☐
	Acceleration Driving Style	The weekly average travelled in kilometers or miles over a period of two months	☑	☐
	Proactive Driving Evaluation	The number of stars that the driving style analysis has given to the acceleration behavior of the driver	☑	☐
	Trip ECO Plus Time of Activation	The number of stars that the driving style analysis has given to the “proactive driving” behavior of the driver	☑	☐
	Trip ECO Time of Activation	The length of time for which ECO PLUS mode was activated during the most recent drive when data was recorded	☑	☐
	Trip Electric Energy Consumption Comfort	The electrical energy consumption (kWh) in COMFORT mode measured	☑	☐
	Trip Electric Energy Consumption Overall	The total energy consumption in kilowatt hours (kWh)	☑	☐
	Trip Fuel Consumption	The fuel consumption in liters or gallons during the last drive logged	☑	☐
	Trip Mileage	The total mileage after the last drive logged	☑	☐
	Trip Electric Driven Distance	The percentage of distance covered with electrical energy during the most recent drive	☑	☐
	Last Drive Energy Recuperation	The average electrical energy in kilowatt hours recuperated during the last logged drive	☑	☐
	HV Battery Charging Status	The charging status (in percentage) of the high-voltage battery at the end of the most recently logged drive	☑	☐
	Recent Drive Time	The date and local time of the most recently logged and transmitted drive	☑	☐

[1] including vehicles of the MINI brand
[2] refers to the vehicle’s trip statistics data (Otonomo)

Table A.5: Available data of Mercedes-Benz & BMW/MINI vehicles via neutral servers 5, Sources: [97, 96, 59, 60]

Use-case	Attribute	Description	BMW[1]	MB
Electric Vehicle Status	State of charge	Percentage of total tank capacity	☑	☑
	Charging Status	The current charging status of the vehicle	☑	☐
	Electrical Range	Approximate distance an electric vehicle can drive before running out of battery	☑	☑

[1] including vehicles of the MINI brand

Table A.6: Available data of Mercedes-Benz & BMW/MINI vehicles via neutral servers 6, Sources: [97, 96, 59, 60]

B Mail communication

B.1 Otonomo

Von: [redacted] <[redacted]@otonomo.io>
Gesendet: Dienstag, 2. Juni 2020 09:10
An: fd033@hdm-stuttgart.de
Betreff: Re: Personal Services: Which OEMs are currently supported?

Hi Felix.

Other brands are supported but we are not allowed to communicate any name.

Best Regards,
[redacted]

If you do not wish to receive further emails, kindly reply with "Leave Out" or "Unsubscribe"

signature_658538121

[redacted]@otonomo.io

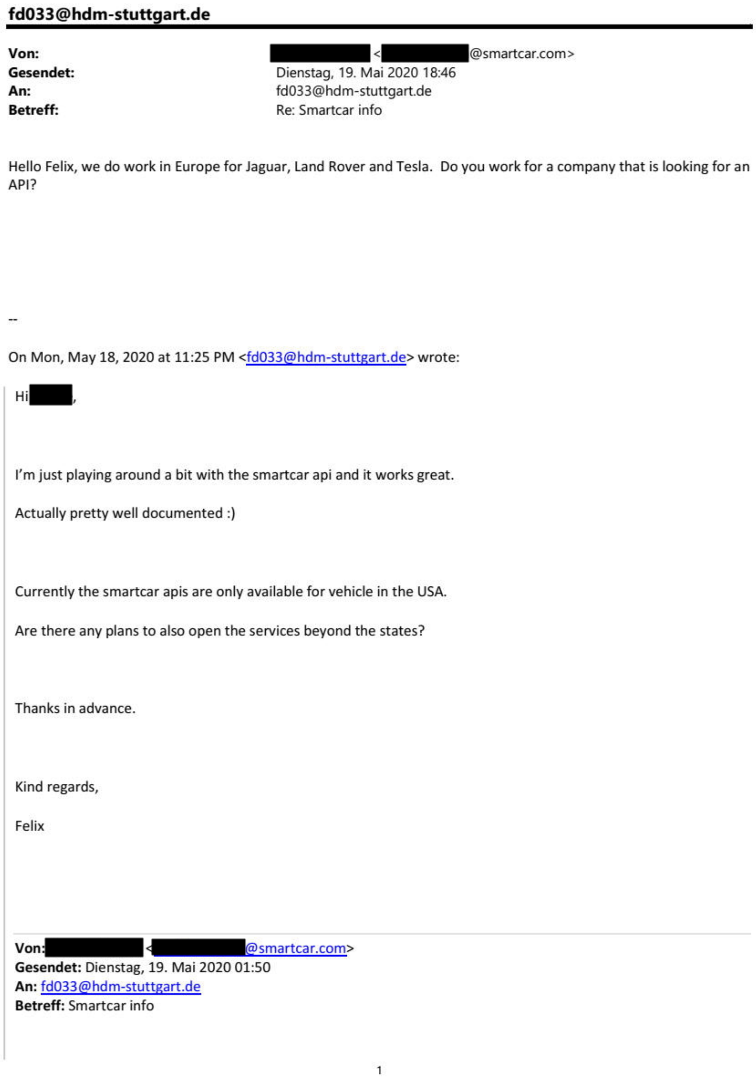
From: fd033@hdm-stuttgart.de <fd033@hdm-stuttgart.de>
Sent: Tuesday, June 2, 2020 10:05 AM
To: [redacted] <[redacted]@otonomo.io>
Subject: AW: Personal Services: Which OEMs are currently supported?

Mhh okay, thank you.
I am just wondering if personal vehicle data is currently restricted on Mercedes-Benz and BMW/Mini vehicles or if other brand are also supported?

Kind regards,
Felix

Figure B.1: Personal communication about personal service OEM support

B.2 Smartcar



fd033@hdm-stuttgart.de

Von:	[redacted] <[redacted]@smartcar.com>
Gesendet:	Dienstag, 19. Mai 2020 18:46
An:	fd033@hdm-stuttgart.de
Betreff:	Re: Smartcar info

Hello Felix, we do work in Europe for Jaguar, Land Rover and Tesla. Do you work for a company that is looking for an API?

--

On Mon, May 18, 2020 at 11:25 PM <fd033@hdm-stuttgart.de> wrote:

> Hi [redacted],
>
> I'm just playing around a bit with the smartcar api and it works great.
>
> Actually pretty well documented :)
>
> Currently the smartcar apis are only available for vehicle in the USA.
>
> Are there any plans to also open the services beyond the states?
>
> Thanks in advance.
>
> Kind regards,
>
> Felix
>
> **Von:** [redacted] <[redacted]@smartcar.com>
> **Gesendet:** Dienstag, 19. Mai 2020 01:50
> **An:** fd033@hdm-stuttgart.de
> **Betreff:** Smartcar info

1

Figure B.2: Personal communication about Europe Support 1

Hi Felix, thank you for visiting Smartcar and testing our product. Are there any questions or feedback you have? I would be happy to schedule a quick chat this week.

Best,
[redacted]
Smartcar

Best,

[redacted]

Smartcar

408.341.9770 Direct

smartcar

Best,
[redacted]
Smartcar
408.341.9770 Direct

smartcar

This message and its attachment(s) are confidential and may contain privileged information for the sole use of the intended recipient.

Figure B.3: Personal communication about Europe Support 2

C Expert interviews

C.1 Jaguar Landrover interview guide

Interviewleitfaden Jaguar Land Rover

Forschungsgebiet

Connected Car API – Plattformen

Einstieg

- Begrüßung und Dank für die Zeit
- Kurze Vorstellung der Bachelorarbeit
- Kurze Beschreibung des Interviewablaufs und der ungefähren Dauer
- Datenschutzvereinbarung

Einstiegsfragen:

- Wie lange arbeiten Sie schon im Bereich von vernetzten Fahrzeugschnittstellen?
- Was sind Ihre täglichen Aufgaben bei Jaguar Land Rover?

Schlüsselfragen:

- Einige Hersteller bieten mit ihrer eigenen Connected Car API Plattform Zugriff auf ihre Fahrzeuge. Was spricht für und gegen solch eine herstellereigene API-Plattform?
  Wie steht JLR dazu?
- Die bisherigen Anwendungsfälle für die Nutzung einer Connected-Car-API-Plattform generell sind recht überschaubar (z.B. Auto-Versicherungen, Carsharing, E-Mobilität, Flottenmanagement, Diagnostik & Wartung)
  Was sind die perspektivischen Anwendungsfälle dahinter?
- Erst kürzlich hat die CC-API Plattform „smartcar“ die Integration von JLR Fahrzeugen veröffentlicht. Was war die Motivation dahinter?
- Wie offen ist JLR für weitere Partnerschaften mit weiteren API Plattformen wie High Mobility?
- Welchen Mehrwert haben OEMs den Zugriff auf ihre Fahrzeuge über herstellerübergreifende API-Plattformen wie High Mobility oder smartcar zu ermöglichen?
- Wie gut ist die Zusammenarbeit zwischen den OEMs und den herstellerübergreifenden API-Plattformen? Wie hoch ist die Bereitschaft der OEMs Daten zu teilen?
- In wie weit sieht JLR Anbieter wie Otonomo, smartcar oder High Mobility als Konkurrenz zu eigenen Services und als Gefährdung der Datenhoheit?
- Wie verträgt sich deren Geschäftsmodell mit dem Interesse der OEMs selber die Daten zu monetarisieren bzw. exklusiv zu nutzen?
- Ist die Anbindung an herstellerübergreifende CC-API-Plattformen rechtlich motiviert oder erwarten OEMs hier eine Monetarisierungsquelle für die eigenen Daten?
- Sehen Sie generelle Unterschiede, Vor- & Nachteile der einzelnen Anbieter – aus OEM Sicht?
- Wie wird sich das Datenvolumen & die Anzahl der Attribute in der Zukunft verändern/erweitern - Welche Daten plant JLR zukünftig bereitzustellen? Auch Daten aus Fahrassistenz-Systemen und weiteren Sensoren?
- Für die Unterstützung der Connected-Car IT-Infrastruktur gibt es verschiedene Anbieter wie Amazon oder Microsoft. Wie ist das bei JLR organisiert?
- Es gibt verschiedene Richtlinien, internationale Standards & Initiativen die sich für eine einheitliche Vernetzung von Fahrzeugen und einer neutralen Verfügbarkeit der Daten

Felix Dimmler Connected Car API - Plattformen fd033@hdm-stuttgart.de

C.2 Jaguar Landrover interview answers

Interview Answers Jaguar Land Rover

Field of research

Connected Car API – Platforms

Entry questions:

- How long have you been working in the field of connected vehicle interfaces?
  - 2 years with JLR
  - 7-8 years in the Connected Cars sector
- What are your daily tasks at Jaguar Land Rover?
  Maintain, development & support of the internal API interfaces at JLR
  - Maintenance, coordination of the development teams
  - Cybersecurity

Key questions:

- Some manufacturers offer access to their vehicles with their own Connected Car API platform. What are the pros and cons of such a manufacturer's own API platform?
  What is JLR's position on this?
  - JLR has no public API platforms planned
  - Reverse engineering of JLR APIs is available on the web
    - This makes the developer community and the need clearly visible and is also monitored by JLR
    - This developer community also makes feature requests to JLR, but usually cannot implement them, which is why the X-OEM platforms comes into play here.
  - An OEM platform can offer services better tailored to the vehicle e.g. sharpen the theft warning: Just not only vibration, but also when someone grabs the door handle
  - Advantage of cross-platforms are normalized APIs for any vehicle – the complexity is abstracted away and it is easier to develop
  - Improvement specialization of developer experience
  - Potential customer base >15 million vehicles compared to 500k JLR vehicles
- The existing use cases for the use of a connected car API platform are quite limited (e.g. car insurance, car sharing, e-mobility, fleet management, diagnostics & maintenance)
  What are the perspective use cases behind them?
  Do you think end customers are willing to bear the costs of networking?
  - At present, this must be developed
  - Potential is not yet really recognized on the market
  - Comparison with Smart-Home: What can I really do with the possibilities?
    - There are no really big investments in this area yet
    - There are still no real use cases for everyone - they are always niche use cases
    - Certainly also country-specific: Panic in Germany
      "I want to monitor my vehicle – but I do not want to be monitored"
  - According to costs - this depends on the application:
    - But generally comparable to streaming services

            - As soon as people have an advantage or a relief in everyday life and the price is reasonable, customers are willing to spend money for it
            - Comparison to OEM Services:
              e.g. theft warning on the smartphone or export logbook / private trip marking Saves lifetime, provides security
            - The advantage here is that this is already priced into the development in the calculation (this would not have been the case with a data product)

- Just recently the CC-API platform "Smartcar" has released the integration of JLR vehicles. What was the motivation behind it?
    - There is no official partnership known between JLR and Smartcar for using the JLR APIs.
    - In general, the generalized APIs are not yet considered an additional sales channel for JLR.
- How open is JLR to further partnerships with other API platforms like High Mobility?
    - No active discussions known
    - A data platform interface to X-OEM providers significantly adds additional effort & costs to maintain the interfaces according to maintenance cycles etc.
    - Constant communication between OEM and third parties about changes, revision of APIs needed
    - With middlemen it becomes more complicated to maintain the APIs
    - JRL is regularly in discussions with the usual suspects. But the business models currently do not - yet - justify the effort of integration.
- What added value do OEMs have in enabling access to their vehicles via cross-manufacturer API platforms such as High Mobility or Smartcar?
    - For now this is a niche market: individual developers e.g. Smarthome
    - Great potential for X-OEM platforms, which then implement these requirements of individual developers
    - No great added value for JLR apparent, as this is associated with many dangers & concerns
    - Not every service needs to be developed from the OEM on its own, but the OEMs still earns money by providing the access to its vehicles
    - For example, today independent garages buy tools for reading diagnostic data. Tomorrow this could simply be 1000 API requests per month. Today OEMs have no revenue from the tools, tomorrow it could be 10% revenue of a workshop hour.
- How good is the cooperation between the OEMs and the cross-manufacturer API platforms? How willing are the OEMs to share data?
    - Great fear of loose data sovereignty, as high security concerns prevail
    - Own monetization through services is lost
    - Possible uncertainties on the platform that could result in data misuse
    - Incorrect data can be released
    - Once data access is granted, it is difficult to restrict it again
    - But also great danger for OEMs who go their own way with proprietary solutions (e.g. JLR ~500,000 vehicles vs. x-platform). If services that use cross-manufacturer APIs gain in popularity, the market trend will only follow, as a single manufacturer can cover a much smaller vehicle range.
    - JLR has no chance to gain a foothold and make money - JLR produces only about 500,000 vehicles per year

    - Additional danger, as monetization is limited by X-OEM interfaces, as the developer community is limited by Smartcar & Otonomo etc. develop services themselves instead of using proprietary services of the OEM
    - Developer view:
        - Niche from niche - only individual developers who would use the proprietary API platform as a hobby
        - no monetization possible as an own platform is also connected with costs.
- How does JLR see providers such as Otonomo or High Mobility as competitors to its own services and a threat to data sovereignty?
    - APIs themselves are not considered to be competitors, as JLR itself does not offer data products and does not see any opportunity for monetization in this area
    - Focus on the vehicles
- How is their business model compatible with the interest of the OEMs themselves to monetize or exclusively use the data?
    - The question is rather the higher attractiveness that results from (better) Connected Services
    - Data and APIs are currently not yet considered products - but is generally advisable for an OEM
    - Subscription models currently also work as a source of revenue for JLR Connected Services
    - Accounting models are not yet designed for data interfaces
- How will the data volume & number of attributes change/expand in the future - What data does JLR plan to provide in the future? Also data from driver assistance systems and other sensors?
    - Absolutely. Herbert Diess once said about Tesla: With only 500.000 vehicles on the road today, Tesla already has access to more relevant data than the VW Group. Generally, more details is need to get from the vehicles. At least to optimize the engineering of the vehicles and increase quality. For OEMs, a lot of money is buried in warranty claims. If fewer customers come to the workshop because of defects, it will help the image in the long term, but in the short term it will reduce costs. There are multibillions in it, especially for large OEMs. Money that don't have to spend can be accounted as real 'monetization'.
- For the support of the Connected-Car IT infrastructure there are different providers like Amazon or Microsoft. How is this organized at JLR?
    - There are special providers such as Wireless Car or others. The Tech Giants are pushing into the market, but have nothing on the market yet. VW is building with Microsoft. JLR is in contact with several providers. But there is nothing ready yet - especially no market-proven.
- There are various guidelines, international standards & initiatives that encourage a consistent networking of vehicles and a neutral availability of data. Do you have an opinion why there are no legal obligations (yet)?
    - Before any regulations are in place, it must first be clear which data are valuable or represent added value and what happens with the data
    - There is a tax on energy - why are there no taxes on data yet?
        - So far there is no state of data monetarized. If there were, there would definitely be mandatory guidelines.
    - First of all, there has to be a sense of what data needs to be standardised
    - Therefore, the use case for the data must usually be named before an OEM releases data.

  - What is a legislator able to request the OEMs to provide open data?
    - Risk: e.g. OBD data in the cloud
    - Good: Build usecases on it
  - Disadvantage: Third parties can create automated data analyses and, for example, determine quality characteristics of different brands, models, years of manufacture, regions, etc. and thus possibly damage the reputation of OEMs
  - Risk: Once available data is no longer limitable
    For example, a theft using the example of Otonomo:
    "I need mirrors from JLR vehicles, where can I find them?"
  - Another Risk: Conclusions can be drawn about the person
    When did someone drive too fast or too slow
  - A defined standards can only be established if there are already implementations which already uses this standard
- The "World Wide Web Consortium" (W3C) operates an "Automotive Working Group" on the networked vehicle in which JLR also participates. How active is this working group? What is its motivation? How seriously are the specifications defined there pursued/implemented, e.g. VSS data model?
  - GENIVI VSS data model:
    - The current focus is on: expanding / further developing in-vehicle communication
    - A little bit asleep, because currently hardly any OEM is relying on GENIVI infotainment systems for the future
    - So the VSS is more likely to be on the siding
    - VSS data model is a pull-based interface (constantly listening)
    - REST technology (on-board or off-board) can hardly be mapped in connection with the VSS data model
    - VSS is an in-vehicle interface - driven by GENIVI
  - But currently no longer very active in the W3C, since there will either be proprietary solutions in the future or Google's Android Automotive will be used (trend)
  - W3C:
    - Active participation, great ideas
    - But big players like VW are not as active as they used to be
    - Standards must also be accepted by the community
    - Google is the bigger player and has the bigger community
    - Caution on the part of the OEMS: investments are restricted
    - Standard only helps if there are established companies that use this standard
- How important is the interlocking between the W3C Automotive Working Group and the GENIVI Alliance of the Automotive Industry? And how well does the communication between all parties involved (OEMs, suppliers, etc.) work?
  - Both the W3C and GENIVI alliance need to look at who is active - the same people are not always really active.
  - Difficult discussions in the various committees - tough process ("some want everything, others don't want to give anything")

C.3 Mercedes-Benz interview guide

Interviewleitfaden
Mercedes-Benz /developers

Forschungsgebiet

Connected Car API – Plattformen

Einstieg

- Begrüßung und Dank für die Zeit
- Kurze Vorstellung der Bachelorarbeit
- Kurze Beschreibung des Interviewablaufs und der ungefähren Dauer
- Datenschutzvereinbarung

Einstiegsfragen:

- Wie lange sind Sie schon ein Teil der Mercedes-Benz API-Plattform?
- Was sind ihre täglichen Aufgaben als Product Owner speziell bei Mercedes-Benz Developers?

Schlüsselfragen:

- Welches Ziel bzw. Zielgruppe verfolgt die Mercedes-Benz API-Plattform?
- Die bisherigen Anwendungsfälle für die Nutzung einer Connected-Car-API-Plattform sind recht überschaubar (z.B. Auto-Versicherungen, Carsharing, E-Mobilität, Flottenmanagement, Diagnostik & Wartung)
  Was sind die perspektivischen Anwendungsfälle dahinter?
- Die verfügbaren Fahrzeugattribute werden auf der Plattform in verschiedene APIs und Anwendungsfälle gekapselt.
  Warum kann ich nicht gezielt nur einzelne Attribute abrufen?
- Mit Konfigurator-Daten oder Fahrzeug-Bilder für spezifische Fahrzeuge bietet die Mercedes-Benz API Plattform auch Daten an, die herstellerübergreifenden API-Plattformen nicht zur Verfügung stehen.
  Sehen Sie weitere Vorteile gegenüber herstellerübergreifenden API-Plattformen wie High Mobility?
- Welchen Mehrwert hat Mercedes-Benz Zugriff auf ihre Fahrzeuge über herstellerübergreifende API-Plattformen wie High Mobility zu ermöglichen?
- In wie weit sieht Mercedes-Benz Anbieter wie Otonomo oder High Mobility als Konkurrenz zu eigenen Services und als Gefährdung der Datenhoheit?
- Ist die Anbindung an herstellerübergreifende CC-API-Plattformen rechtlich motiviert oder erwartet Mercedes-Benz hier eine Monetarisierungsquelle für die eigenen Daten?
- Welche weiteren Daten plant Mercedes-Benz zukünftig bereitzustellen? Auch Daten aus Fahrassistenz-Systemen und weiteren Sensoren?
- Bisher können nur B2B-Kunden eine App produktiv schalten.
  Welche Bedingungen/Voraussetzungen sind dafür notwendig?
- In welchen preislichen Rahmen bewegt sich ein Business-Paket einer API (Beispiel Startup zur Nutzung der "Vehicle Status"-API)?
- Wird der Preis hierbei individuell für jeden Partner festgelegt?

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C.4 Mercedes-Benz interview answers

Interview Answers
Mercedes-Benz /developers

Field of research

Connected Car API – Platforms

Entry questions:

- How long have you been a part of the Mercedes-Benz API platform?
  - April 2017 and November 2017
  - Directly become part of the Mercedes-Benz API platform
  - The Mercedes-Benz API platform has been available for approx. End of 2016
- In the beginning, it was called Daimler ONE API?
  - Internal two parts: One API & Open API
  - One API: API Management Platform - Internal API Environment
  - Open API: External, outwardly visible API on the platform
  - Both occur externally as MB API platform
  - However, the Open API builds on the One API
- What are your daily tasks as a product owner especially at Mercedes-Benz Developers?
  - Integrator & Event planner for Mercedes Benz Developers
  - Coordination, coordination of various stakeholders within the company for the sharing of vehicle data.
  - Help integrate data into the portal
  - Identify & evaluate new data sources that might be of interest to the portal
  - Co-development in the design & implementation of the interfaces
  - Support and advancement of the community / social media channels behind the portal
  - Technical support in the implementation of data products
  - Product Owner of the Portal & the High Mobility Simulator

Key questions:

- Which target or target group does the Mercedes-Benz API platform pursue?
  - Earn money
  - B2B Monetization/Collaboration Level
    - Offer data products to other companies that can then develop applications
    - Widely spread from independent Mercedes-Benz dealers to automobile clubs or startups
    - Especially Vehicle Diagnostics
  - Individual developers
    - Support to develop applications for MB vehicles
    - Indirect pushing innovation in Connected Car Services
    - Also, private engagement to enhance connected/mobile car services
    - Open Source - Promoting the idea of innovation
  - B2M - Municipalities
    - Business 2 Government: Provide municipalities with car data

e.g. Winter snow clearing service: Services to enable snow clearing services to predict where clearing is necessary

- The previous use cases for the use of a connected car API platform are quite limited (e.g. car insurance, car-sharing, e-mobility, fleet management, diagnostics & maintenance)
  What are the perspective use cases behind them?
  - No direct answer
- The available vehicle attributes are encapsulated on the platform into various APIs and use cases. Why can't I specifically retrieve only individual attributes?
  - Generally very skeptical to give access to data:
    Security stands for the brand – does not want to risk this privilege
  - Several internal control committee on the release of data
  - The approval process for each use-case:
    - Makes it easy, because it is always predefined what happens with the data
    - This would be more difficult with freely configurable data points
  - Use-cases which are predefined by Daimler:
    - These were assumptions where customers might be interested in and money can be earned – more an inspiration
    - Some use-cases also come through customer request
    - Internal thought movement for free adjustment of data points – but only as an additional offer
    - Partly already possible in the mobile SDKs with hundreds of data points
    - A rethink is taking place to promote innovation - but no concrete plans
    - Since not much has happened in 3 years, so that users can freely put together what they need - similar to Otonomo and High Mobility
- With configurator data or vehicle images for specific vehicles, the Mercedes-Benz API platform also offers data that is not available to cross-manufacturer API platforms.
  Do you see further advantages over cross-manufacturer API platforms such as High Mobility?
  - Generally nothing no reason for not offering these data points to other platforms - up to now there was no need/customer request was part of the business model of High Mobility & Co.
  - An advantage for MB:
    - Generally no direct strategic advantages or disadvantages
    - MB can react faster to customer requirements (changes or feature requests), because directly at the source
    - Close contact with the community – providing data products on customer feedback. High Mobility, on the other hand, may have to pass on requirements to MB first
- What benefit does Mercedes-Benz have in providing access to its vehicles via cross-manufacturer API platforms such as High Mobility?
  - In general, it does not matter to MB whether the data is accessed via a partner or directly via their own platform - the end customer decides
  - More customers through more platforms
  - Visibility as a brand generally - Prestige
  - Legally motivated to provide the data as a forerunner - may become mandatory in the future.
- How many customers come through the multi-vendor platforms?
  - Officially there is no information on how many customers High Mobility has
  - It is only visible how much is sold in total (API calls)

- How does Mercedes-Benz see providers such as Otonomo or High Mobility as competitors to its own services and a threat to data sovereignty?
    - No, because you earn money in both cases
    - In general, it does not matter to MB whether the data is accessed via a partner or directly via the platform - the end customer decides
    - High Mobility & Co. is treated like any other customer
        - Are registered as developers in the portal with a subscription
        - Monetary no disadvantages
    - No direct competition, but another distribution channel - an expansion
    - But direct feedback from the community is missing customers access data through the partners
- Is the connection to manufacturer-independent CC-API platforms legally motivated or does Mercedes-Benz expect a monetization source for its own data here?
    - High Mobility and Co is another sales channel to get more customers
    - Legally motivated to provide the data as a forerunner - may become mandatory in the future.
    - The purpose of the neutral server (which represents High Mobility for Daimler) is that it is not clear which customers use the data and how the data is used. For fear that if Daimler knew what the data was being used for and for which use-case, Daimler could implement the application itself - before the external developer.
    - Daimler is also in continuous exchange with the EU in implementing guidelines as far as possible before they are obligatory - as with the neutral server
    - No statement whether the neutral server concept is mandatory for OEMs, yet
- What does the partnership with Smartcar look like, which is mainly active in the USA?
    - Already have been in discussions with Smartcar, but there is no recent update
    - It is not easy to sell data beyond Europe because the data is not sold as Daimler AG or Mercedes-Benz, but via a subsidiary, the Mercedes Benz Connectivity Services GmbH (MBCS)
    - There are legal reasons for this. At the moment Daimler is only able to do business with the API platform in Europe. This year Daimler is working on selling data in the USA and China. As soon as this is the case, they will get in contact with Smartcar again.
    - The American market is different when it comes to data - more freedom - Especially related to personal data
    - This also has an impact on the portfolio, as more rules must be followed in Europe
- What other data does Mercedes-Benz plan to make available in the future? Also data from driver assistance systems (ADAS) and other sensors?
    - The current trend is towards anonymized data through Car-2-X
        - For example, where are potholes, snowplow management, accidents
        - This is all currently missing in the portfolio - at least in the developer portal
        - But high demand from customers e.g. vehicles send Slippery Road Warning
        - There will be a data product soon for this data
        - Cooperation with map providers e.g. Here Maps so that other vehicles can also benefit from this data
        - This is also a kind of sensor data - However, they are not sold as pure sensor data but are processed via an intermediate layer, as otherwise conclusions about the functioning of a vehicle could be retracted.
    - Fleet management

        - There are already solutions, but they are not yet integrated into the developer portal. So there are considerations to standardize and offer fleet management within Daimler
    - Vehicle/sensor data
        - SDK already offers many data points that are not yet available via the REST interface like opening and closing the vehicle
        - Currently no attempt to share sensor data/driving assistance data - there are high safety concerns
            - However, Daimler is very careful with whom and to what extent this data is shared
            - Once the data is open, it is difficult to restrict it afterward
        - Generally open and willing to share the data
        - CLEPA - European Institution regularly calls for opening these data
            - No need to open data as there is no significant customer demand for it so far
    - Monetarily open to sharing what is requested by customers. Currently, however, the focus is on other products such as fleet management
- How close is the partnership with Otonomo? Is it similar to High Mobility?
    - As a neutral server, they are a great partner
    - High Mobility's special partnership is due to the simulator implementation for the Daimlers Developer platform
    - In consultation with Otonomo, many customer requests are forwarded to Daimler.
- Up to now, only B2B customers have been able to put an app into production. Which conditions/prerequisites are necessary for this?
    - Daimler do have so-called Data Clearing Office & various committees that check the data access
    - Besides, customers are checked (location, origin, segment) before they receive productive access to the data points
    - Sales tax ID required in the European Economic Area
        - The company is easier to check (blacklists etc.)
    - However, other economic areas are generally not excluded
    - For the SDK there is a public 15-page catalog with requirements
    - Call volumes are also part of considerations:
      Must be within reasonable limits, as the connection and the approval process also generates costs for Daimler itself and must be profitable.
    - Approval runs through a Daimler subsidiary Mercedes-Benz Connected Services
    - In retrospect, end customers can check the validity of the data release themselves via the purpose URL which defines for what purpose the application retrieves the data
- What is the price range of an API business package (e.g. startup for using the "Vehicle Status" API)?
    - Using the example of vehicle status & vehicle-related data
        - Accounting according to VIN and month
        - An infinite number of requests per vehicle per month
        - Fixed amount per vehicle
        - Between €0.19-0.39
    - Compared to the public prices on High Mobility:
      High Mobility itself adds only a minimal amount to the prices Daimler charges to High Mobility

  - On the Daimler side, there are various teams (e.g. Aftersales)
    - The API for remote diagnostics support must legally be distributed by Daimler AG and therefore does not work via MBCS
    - Therefore the "remote diagnostics support"- & "remote maintenance support" APIs the prices are publicly available in the Xentry Shop
  - Vehicle Images prices are also public
- Is the price set individually for each partner?
  - Price models are still in the design stage but fixed
  - Volume-related discounts possible
  - In the end, a start-up has the same conditions but enjoys a special status in the initial phase in the Daimler support program
- There are also experimental APIs with the "Connected Vehicle" & "Finance Calculator" - Are there reasons why these APIs are not productively available yet?
  - Initially, these APIs were also planned to go live
  - In the case of "Connected Vehicle":
    - However, due to Cooperate Data Protection and legal obstacles, the API was only provided in the simulation
    - Technically the Connected Vehicle is outdated – Daimler is still looking for alternatives, as it only supports PULL requests and no PUSH requests, which would allow notifications and is a requirement for further implementations
    - In the long term, the extensive functions of the SDK generally also will be made available via REST-API.
- What are the reasons why an API is only available as productive and not in the test environment (e.g. "Electric Vehicle Status")?
  - Time reasons, as there was a deadline constraint from the EU
  - Generally, it is not easy to transfer these APIs into the simulator
- Via High Mobility, there are interfaces that already productively support functions for Mercedes-Benz vehicles that are not yet possible via the manufacturer's own platform (e.g. control of the door lock). Are there reasons for this?
  - This is not correct, because so far this is only possible via the SDK and so High Mobility & Co is not available at all.
- To support the development of CC services, the "powered by High Mobility" vehicle emulator is provided on your API platform. How did the partnership come about? Is the test environment operated at High Mobility?
  - Daimler is currently redesigning their simulator architecture so that the SDK APIs and the REST APIs can be simulated in the same environment and hosted by Daimler itself.
  - By today Daimler has two separate simulators. One for the "connected vehicle" API simulation which is operated and hosted by High Mobility, and the new one.
  - The new simulation of Daimler is also built by High Mobility but hosted internally at Daimler which is already live for the new mobile SDK test environment.
  - The Partnership with High Mobility was established through the simulator in 2017
  - Neutral server principle provided by High Mobility was added later
- Is there a reason why the emulator should be active to experiment with the APIs (especially with the Connected Vehicle API)?
  - Yes, technical reasons, as there is no persistence in the backend
  - In the new environment, this is will be possible without an active simulator
- With the Daimler Vehicle Backend (DaiVB), Daimler covers the IT infrastructure of its networked vehicles.

- Is the Mercedes-Benz API platform also integrated into this infrastructure?
    - This environment is now called MBIC - Mercedes-Benz Intelligent Cloud
    - This is the data pool from which all applications at Daimler, that have anything to do with vehicles draw their data from.
- On the official Mercedes-Benz Developer Twitter channel an API platform was announced also for private used cars - "BYOCAR" - what is the motivation?
    - „Bring your own car“
    - Process costs for the B2B approval process are too high for individual developers, which is why individual developers with great ideas have so far had to be rejected
    - To provide a free opportunity for individual developers or companies with their real vehicles to test the data products easily and productively without approval procedures - especially the API which currently has no simulator support.
    - This platform will be an additional service related to Mercedes-Benz data products like - Fuel status, Electric Vehicle, Pay as you Drive, etc.
    - To provide also a simulator for this would then be the next step in this new offer

C.5 High Mobility interview guide

Interviewleitfaden High Mobility

Forschungsgebiet

Connected Car API – Plattformen

Einstieg

- Begrüßung
- Kurze Vorstellung der Bachelorarbeit
- Kurze Beschreibung des Interviewablaufs und der ungefähren Dauer
- Datenschutzvereinbarung

Einstiegsfragen

- Wie lange sind Sie bereits Teil von High Mobility?
- Was genau sind Ihre täglichen Aufgaben?

Schlüsselfragen

- Welches Ziel bzw. Zielgruppe verfolgt High Mobility allgemein mit ihrer API-Plattform?
- Die bisherigen Anwendungsfälle für die Nutzung einer Connected-Car-API-Plattform sind recht überschaubar (z.B. Auto-Versicherungen, Carsharing, E-Mobilität, Flottenmanagement, Diagnostik & Wartung)
  Was sind die perspektivischen Anwendungsfälle dahinter?
- Gibt es bereits konkrete Kunden, Showcases die die API-Plattform nutzen?
- Mit „Smartcar" gibt es in den USA ein ähnliches Konzept. Wie unterscheidet sich High Mobility im Vergleich zu anderen Anbietern von CC-APIs?
- Der Verbund von mehrere Hersteller innerhalb einer Plattform hat den Vorteil der einfachen Skalierbarkeit einer Anwendung. Sehen Sie weitere Vorteile im Vergleich zu den Plattformen der Hersteller selbst?
- Welchen Mehrwert haben OEMs wie Mercedes-Benz oder BMW Zugriff auf ihre Fahrzeuge über High Mobility zu ermöglichen?
- Wie gut ist die Zusammenarbeit mit den OEMs, wie hoch ist die Bereitschaft der OEMs Daten zu liefern?
- Wie verträgt sich das High Mobility Geschäftsmodell mit dem Interesse der OEMs selber die Daten zu monetarisieren bzw. exklusiv zu nutzen?
- Wie wird sich das Datenvolumen & die Anzahl der Attribute in der Zukunft verändern/erweitern?
- Auf der High Mobility Webseite sind die Preismodelle aufgelistet.
  Warum sind die Preismodelle an Anwendungsfälle gekoppelt?
  Warum kann ich nicht gezielt nur einzelne Attribute abrufen?
- Haben Sie eine Einschätzung wer am Ende die Kosten für die Vernetzung trägt?
  (z.B. Abo-Modelle für den Endkunden, Dienstleister)
- Kann ich auch privat eine App auf der Plattform produktiv schalten?
  Welche Bedingungen/Voraussetzungen sind allgemein dafür notwendig?
- High Mobility bietet die Möglichkeit auch über Bluetooth auf Fahrzeuge zuzugreifen.
  Was genau sind Anwendungsfälle für die Nutzung dieser APIs (Car SDK & Device SDKs Python SDK)?

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C.6 High Mobility interview answers

Interview Answers High Mobility

Entry questions:

- How long have you been part of High Mobility?
  - Since April 2019
- What exactly are your daily tasks?
  - Sales & Business Development
    - Encourage OEM cooperation as a data provider
    - Encourage data customers ecosystem e.g. insurances, car rental/mobility provider, dealers, maintenance/diagnostic
  - Previously also worked in the area of e-mobility & software development

Key questions

- What goal or target group does High Mobility generally pursue with its API platform?
  - Vehicle data marketplace and neutral server provider
  - Neutral Server:
    - the data recipient is not known to the OEM, only the data purpose and HM.
    - Neutral Server is only a commitment:
      This is implemented to differing degrees by the OEMs. Some are not yet even technically able to provide the data.
  - Aim of HM:
    - To integrate as many OEM interfaces as possible
  - Target group:
    Insurance companies, fleet operators, car rental, car sharing, e-mobility providers, maintenance environments like dealers & workshop chains
  - Specialized in personalized vehicle data: Data that is linked to a specific VIN.
  - But also activities in the field of anonymized data:
    - This will be available in summer
    - But is not a priority compared to personalized data
- The existing use cases for using a Connected Car API platform are quite limited (e.g. car insurance, car-sharing, e-mobility, fleet management, diagnostics & maintenance)
  What are the perspective use cases behind it?
  - Theoretical use-cases are much more diverse
  - Currently limited by the limited release of data & permissions of the OEMs, as they only provide a section of it
  - The platform is already prepared for the requirements of the following next years to implement more data points and write access for remote control (remote start/stop door locks etc.), which is currently not possible
  - When the OEMs will release more data, the use-cases become more diverse.
  - There is an extreme need for car sharing & car rental services to be able to open and close vehicles without proprietary hardware. However, this is not yet approved by the OEM
  - It is hoped that this will be much easier in the future
  - Another example is the anticipation of vehicle maintenance to analyze sensor data. There is also a great need here for companies that want to analyze battery data from electric vehicles to analyze the state of health - including data that has not yet been released.

- Are there already concrete customers, showcases using the API platform?
    - Some customers are not willing to be named as a reference
    - E.g. insurance: “PayDrive” for example offers pay-as-you-drive service by data based on High Mobility
    - Berlin startup “Vimcar”: Offers electronic logbook which uses telematics data based on High Mobility data besides ODB-proprietary hardware dongles.
- What is the feedback of customers?
    - The integration and the access of data via APIs is much easier to implement and therefore also cheaper than proprietary hardware
    - But Sixt, for instance, is due to limited data access not able to rely on telematics data only yet and have to continue using proprietary hardware solutions for their needs
    - Car rentals need data from GPS, maintenance status in certain intervals, but some OEMs are not able or willing to deliver the date regarding their requirements.
    - Simplifying complexity to connect various OEMs with one implementation, because individual APIs of the OEMs are much more complicated – also in the documentation
- With "Smartcar" there is a similar concept in the USA. How does High Mobility differ from other providers of CC-APIs?
  Differentiation with Smartcar:
    - High Mobility is more partnership-oriented due to binding contracts with OEMs, which are necessary for integration in the platform.
    - High Mobility does not use reverse engineering, as is supposed to be the case with Smartcar. Connection via unofficial, reverse-engineered APIs would be out of the question, because none of their customers would accept that it.
    - With no partnerships and unofficial APIs, the integration always have to keep in mind the uncertainty that the interface could be switched off or the data frequency changes (e.g. from hourly update to daily update)
    - Example: Tesla:
        - Open Reverse Engineered API in the web
        - High Mobility would never use it
    - This is also an advantage of High Mobility:
      Legally binding partnerships and contractual guarantees on the operation of the APIs
    - Smartcar technically very similar to High Mobility and also very good and transparent developer setup
    - Only High Mobility has a different commercial approach and relies on binding partnerships
- Differentiation with Otonomo:
    - Otonomo is the strongest competitor and is significantly larger in organization
    - Since very similar OEMs are currently involved, the manufacturer coverage is at a similar level and also addresses similar target groups
    - High Mobility assumes that the integrated OEMs will differ in the future and additionally distinguishing the platform from others by being more user-friendly, approachable and transparent to give customers & developers easy access to the data
    - High Mobility also appeals to smaller companies and start-ups. Otonomo rather targets larger companies
    - Also, the support does not cost money with High Mobility

- The combination of several manufacturers within one platform has the advantage of easy scalability of an application. Do you see other advantages compared to proprietary platforms of the manufacturers themselves?
    - As more OEMs are partnering with High Mobility the more added value customers have
    - High Mobility reduces complexity and tries to offer as developer-friendly as possible interfaces based on their development experience also to distinguish from other API platforms.
    - Quick and easy access to vehicle data due to well-documented tutorials, code examples and more
    - A High Mobility integration effort is much less than those of the OEMs itself.
    - Open Source community and transparency
    - Free development and test platform with vehicle emulators and individually configurable simulation scenarios (e.g. simulate an accident for insurance customers)
- What added value do OEMs have in enabling access to their vehicles via cross-manufacturer API platforms such as High Mobility or Smartcar?
    - In partnership with High Mobility, the OEMs can see which data is requested, relevant and valuable to analyze customer needs and develop new use-cases
- How good is the cooperation with OEMs, how willing are OEMs to provide data?
    - This depends on the OEMs
    - BMW CarData is quite well standardized
    - Tight partnership with Daimler to exchange market feedback and develop new use-cases in cooperation
    - Other OEMs are mainly open for feedback and consulting services
    - But some OEMs are not easily accessible to get their interests in potential partnerships
- How is the High Mobility business model compatible with the interest of the OEMs themselves to monetize or exclusively use the data?
    - OEMs will still prioritize their own data platform
    - The demand will change to cross-platform services for several vehicle brands. But some bulk data customers surely will still stick to one or two vehicle brands. But this individual OEM integration is much more complex and expensive.
    - The platform model will be a particularly promising alternative for data consumers with a heterogeneous fleet and can operate as a multiplier of OEM data.
    - Therefore OEM data business and cross-platform data business will certainly have a co-existence.
- Is High Mobility and Co saw as a competitor to the OEMs?
    - This is controlled by the OEMs themselves. Some use-cases or target groups for instance are only provided by the OEMs itself.
    - From time to time OEMs realizing that High Mobility is rather a multiplier of their data than a competitor. Each API access High Mobility is offering will also be accounted on the OEM side. The pricing for High Mobility is defined by the OEM. Therefore OEMs do not have any disadvantages.
- How will the data volume & the number of attributes change/expand in the future?
    - Realistically planning needed with an estimation what the OEMs are willing to share in the future
    - Currently, there are plans for real-time data, e.g. to track fleet vehicles (rental vehicles). Besides also data for damage claim settlement to analyze accident &

    - failure data of vehicles to be able to make rough damage calculations. High Mobility already knows that some OEMs are willing to share this data with us.
    - Use-cases, where write access to the vehicle, is required (open/close/start/stop): Trunk delivery, logistics, carsharing/car rent or workshops that want to change maintenance data by writing
    - There is a lot of negotiation, but often it is not clear how and when these more sensitive data will be released.
- The price models are listed on the High Mobility website.
  Why are the price models linked to use cases?
  Why can I not specifically retrieve individual attributes?
    - Price models are tailored to the use-cases because the OEMs' price models determine this
    - However, this differs greatly between the manufacturers, which is why it is difficult for us to create a general pricing model for all OEMs. Harmonization expected for the next years
    - Data is always tailored for specific use-cases and must not be used for other purposes. But a combination of several attribute packages is possible.
- Do you have an estimation of who will bear the costs in the end?
  (e.g. subscription models for the end customer, service provider)
    - Depends on the use-case:
        - Cost savings due to process simplification e.g. insurances for claims settlement:
          Therefore the costs are not borne by the end customer, but are part of the re-financing of the cost-savings or will be borne by the data consumer itself.
        - Additional service for end-customer:
          Cost is borne by the end-customer through advertising or is integrated into the service pricing models.
- Is it also possible to go live with an application on the platform privately?
    - The test environment and platform is open for everyone
    - But productive access is reserved for B2B customers
- Which conditions/prerequisites are generally necessary for this?
    - As only B2B can use the services productively, company data and an official Sales tax ID is required
- High Mobility offers the possibility to access vehicles via Bluetooth.
  What exactly are the use cases for using these APIs (Car SDK & Device SDKs Python SDK)?
    - This is historical – at the beginning of High Mobility, this was the first product that made it possible to access data and remote control vehicles by Bluetooth. The car rental service Sixt was one of the first customers and is still using this for their own telematics services with proprietary hardware.
    - Is also used in combination with telematics service to get data access via telematics is offline or disabled
    - High Mobility is still offering these services, but due to telematics services, the demand for Bluetooth solutions decreases.
    - Focus is on the further development of the neutral server & data marketplace
- For the development with the High Mobility APIs, an emulator is provided for different vehicles and services. Besides BMW and Mercedes-Benz there is also the possibility to address Porsche & KTM vehicles and the IOTA blockchain cloud virtually:
  How open is High Mobility for further partnerships with other OEMs or services?
    - High Mobility is in constant communication with new OEMs

    - New data categories and new ways of gathering data through new data channels such as Android Automotive: Data will be delivered from the vehicle directly and not via external cloud systems.
    - Integration of new vehicle classes like light and heavy commercial vehicles and motorcycles
    - Deliver new services of static vehicle information with new partner & investor “DAT”
- Are there any requirements that have to be fulfilled for integration into the platform?
    - The focus is on expanding the brand variety to get more relevant for customers
    - Therefore new partners only need to be able to deliver data via any interfaces (without proprietary hardware)
- How do the requirements for productive availability of an OEM/service differ? Or is this decision in the OEM/Service's own hands?
    - The review process includes reviews related to the end-customer but also commitments to the OEMs:
        - Privacy policy GDPR compliance due to processing of personalized data
        - Correct implementation of the consent flow
        - Transparent access to terms of condition
        - Check if OEM provided data is processed for predefined purposes
- The Mercedes-Benz API platform uses the "powered by High Mobility" vehicle emulator to simulate vehicle communication. How did the partnership & integration come up? And will this service be included in the portfolio to offer this to other manufacturers/configurators? Is High Mobility also willing to provide aggregate data in the future?
    - On-demand, this option would also be available for other manufacturers
    - High Mobility integrated emulators for other OEMs as well, but in internal non-public environments
- Can you tell me something about demand growth?
    - The demand becomes more and more, much stronger than what can be offered
    - A lot more use-cases and potential customers are requesting services, but High Mobility often is not yet able to meet their requirements due to OEM restricted data. That is why High Mobility constantly tries to push the OEMs for more data access.
    - But it is commonly known that the data access and the range of OEMs are still quite limited. Therefore the demand growth is moderate. But this will change with the further integrations of additional OEMs. High Mobility will integrate new partners soon this year.
- Do OEMs inquire also on their own – may be ones which are not as experienced in connected services?
    - That is also the case, but High Mobility usually is the enquirer

D Implementation front-end web application

D.1 Mercedes-Benz /developers API

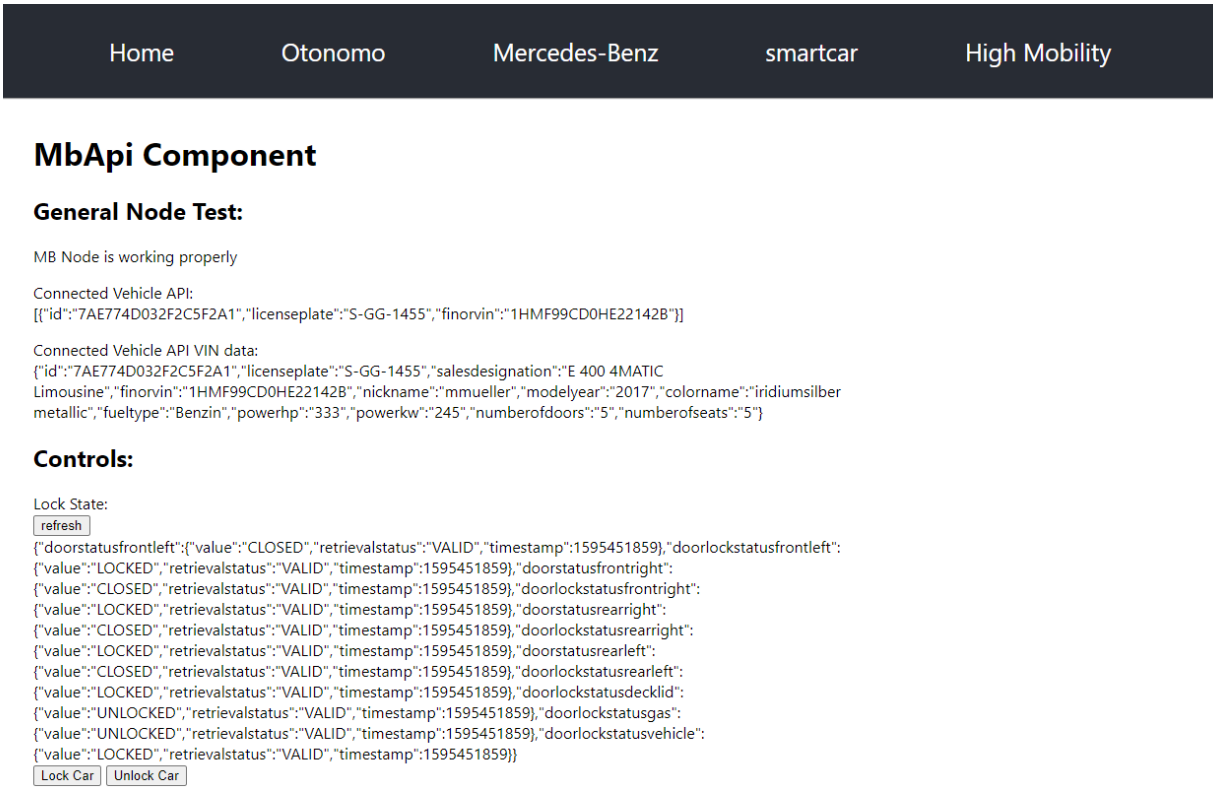

Figure D.1: Mercedes-Benz /developers API implementation

D.2 High Mobility API

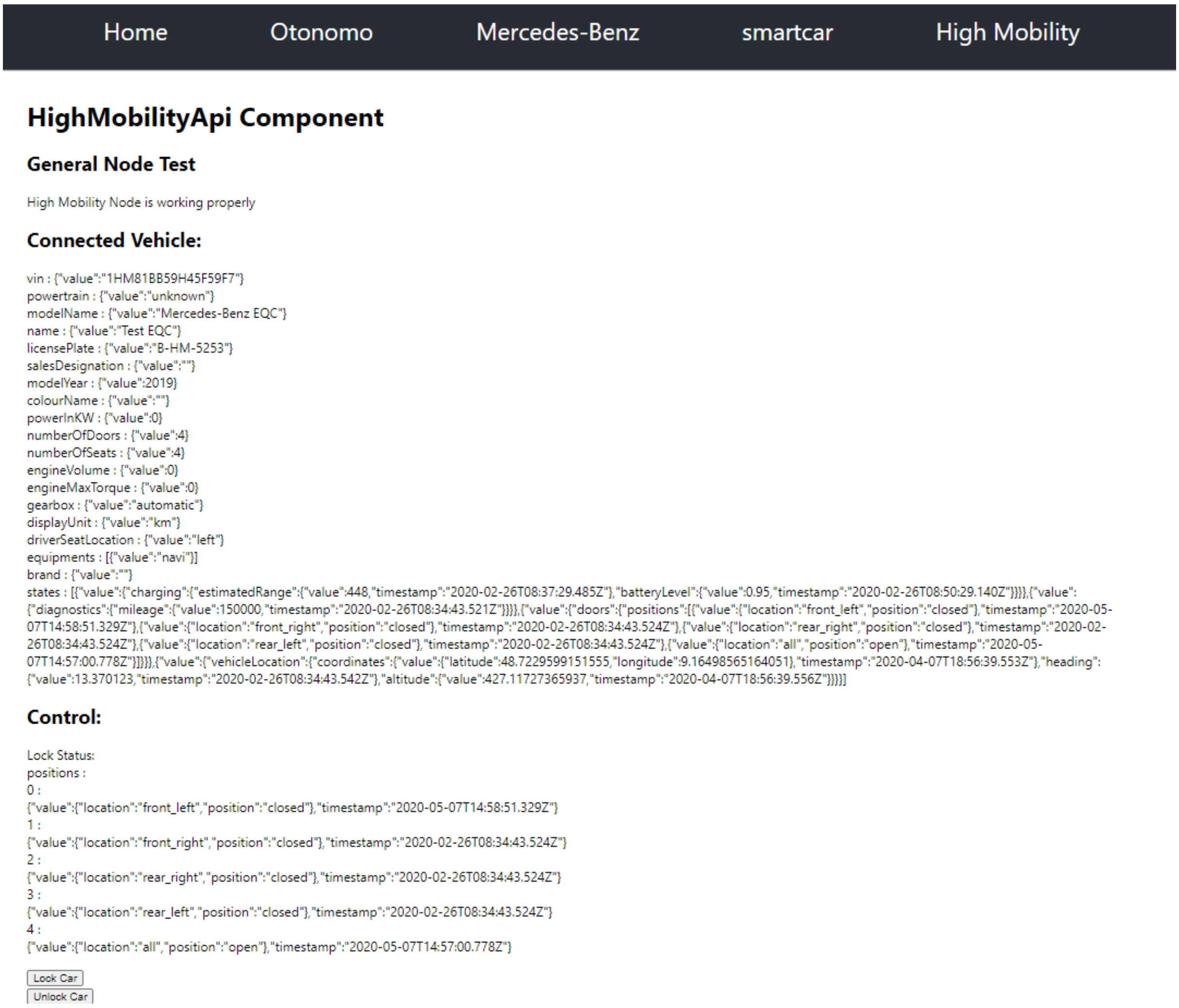

Figure D.2: High Mobility API implementation

D.3 Otonomo API

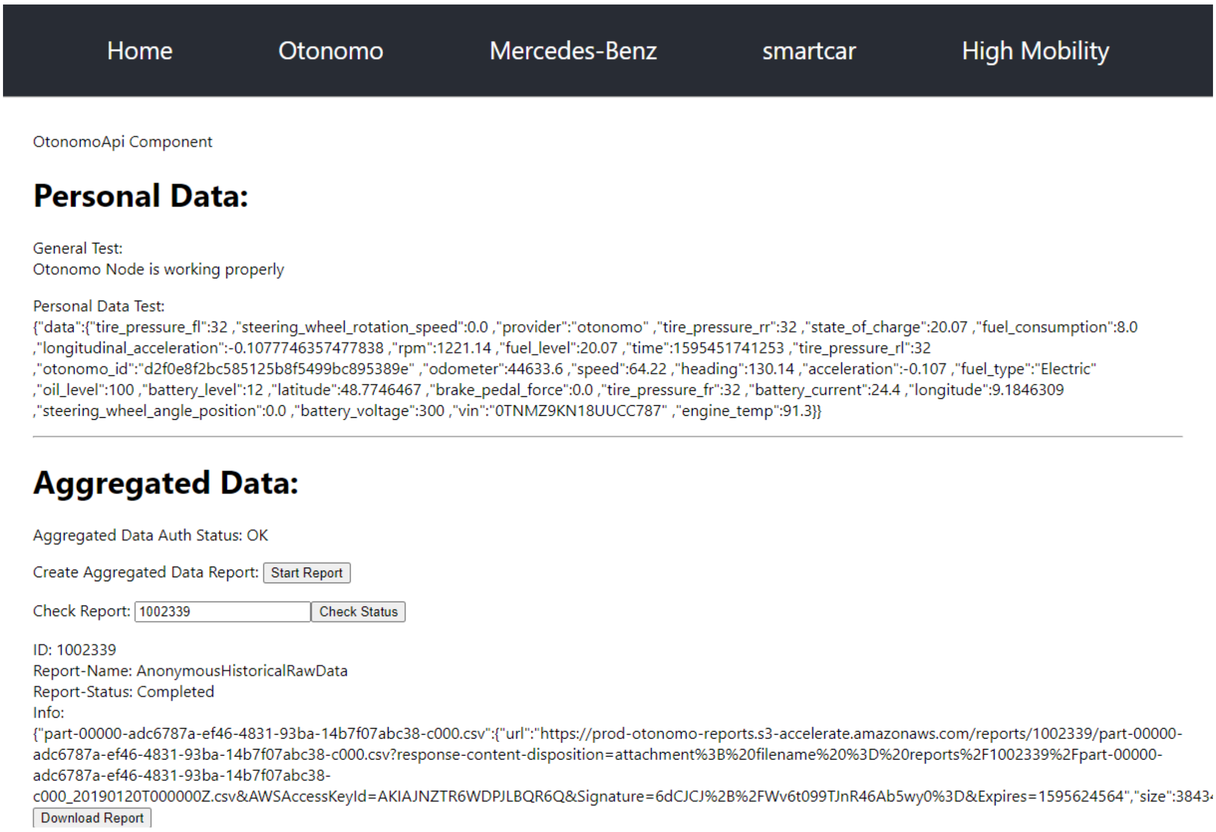

Figure D.3: Otonomo API implementation

D.4 Smartcar API

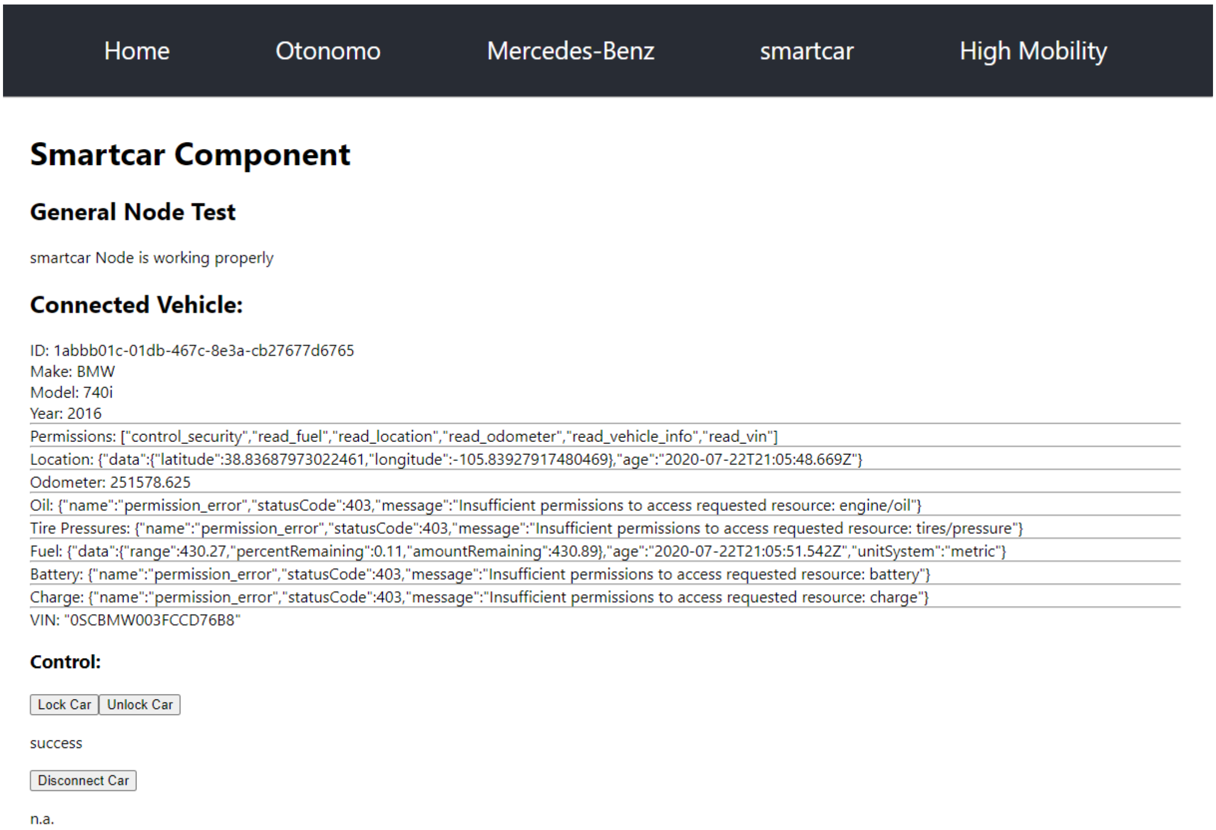

Figure D.4: Smartcar API implementation