The Vehicle Data Value Chain as a Lightweight Model to Describe Digital Vehicle Services

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Abstract: Digitalization has become an important driver of innovation in the automotive industry. For instance, the Quantified Self-movement has recently started spreading to the automotive domain, resulting in the provision of novel digital vehicle services for various stakeholders such as individual drivers and insurance companies. In this direction, a growing number of ICT start-ups from outside Europe have entered the market. Their digital vehicle services are grounded on the availability of vehicle Big Data. Hence, to better understand and capture this ongoing digital transformation, we introduce the Vehicle Data Value Chain (VDVC) as a lightweight model to describe and examine digital vehicle services. Furthermore, we classify current digital vehicle services offered by four start-ups and five car manufacturers by applying the VDVC, thereby identifying commonalities and differences within three crucial steps: data generation, acquisition, and usage. Additionally, we apply the VDVC to describe a digital mobility service provided by a European industry consortium. This exemplary application serves to evaluate the VDVC and show its general applicability in a practical context. We end our paper with a brief conclusion and an outlook on various current activities of standardization organizations, the European Commission and car manufacturers related to the future of vehicle services.

1 INTRODUCTION

Digitalization is an important driver of innovation within all industries, including the automotive industry (Accenture, 2016). While many digitalization challenges in the automotive industry are currently focused on bringing highly automated driving into practice (McKinsey and Company, 2016), it is also a crucial topic of research to explore how and which digital vehicle services can improve the current practice of manual driving or even enable novel applications for other stakeholders and other markets outside the automotive domain.

The ongoing digitalization of passenger cars could even rearrange stakeholder power relations in the automotive industry. In the last decade, numerous IT start-ups from outside Europe have created several interesting digital services, exploiting data gained from the vehicle on-board diagnostic (OBD) interface, from additional sensors built into a connected OBD plug-in device and/or from the driver's smartphone. This could lead to new business models emerging in the automotive domain, some of which have already attracted the attention of car manufacturers. One prominent example is BMW i Ventures and its recent investments in start-ups such as Zendrive (2017) and Nauto (2017).

Two current key drivers of digitalization in the automotive domain are the ever-increasing amount of vehicle data generated and the capability of modern information and communication technologies (ICT) to transform these data into business value for various stakeholder groups. These may include individual stakeholders (e.g. vehicle drivers) as well as

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organizational stakeholders (e.g. insurance companies, infrastructure operators, or traffic operators). “Modern vehicles have up to one hundred on board control units that constantly communicate with each other to ensure the correct driving and customer functionality” (VDA, 2016). Hence, vehicles are already generating vast amounts of data using in-vehicle sensors. Certain parts of these data are safety-critical and will therefore not be allowed to leave the passenger car, while the remainder can and will be utilized to establish novel digital vehicle services (as indicated by the European Parliament in Directive 2010/40/EU (EU 2013)), which can go far beyond merely assuring driving functionality and safety.

Digital Vehicle Services are data processing services operating inter alia on vehicle data, which can provide added value to those consuming them. In this context, the term ‘service’ can be considered from two different points of view: On the one hand, a ‘service’ is understood as a piece of software applying approaches from computer science to transform and merge different sources of data (be it raw or pre-processed) into new, enriched forms of aggregated data. If done correctly, the value of these enriched data is inherently higher than the sum of values of the single datasets which were combined in the process. On the other hand, a ‘service’ is understood as something of economic relevance, providing an added value to one or more stakeholder groups as a service offering.

While the enormous amount of data available today enables the creation of valuable digital services in the first place, it also poses a great challenge with regard to data processing. To create value, data must be acquired, transformed, anonymized, annotated, cleaned, normalized, aggregated, analyzed, appropriately stored and finally presented to the end user in a meaningful way. This implies that an entire data value chain needs to be created, implemented and monitored. With this in mind, we analyze, summarize and provide insights into how existing initiatives on the market tackle this challenge. Hence, we aim to answer the following research question from the emerging field of digital vehicle services research: *What is the underlying data value chain enabling digital vehicle services and how can it be applied to describe existing services?*

To answer this research question, we first review the literature on relevant concepts for digital vehicle services, including Quantified Self, Big Data, and the Internet of Things. Based on the Big Data Value Chain as described by Curry (2016), we derive a *Vehicle Data Value Chain (VDVC)* that is intended to provide a structure and a frame of reference allowing to systematically describe the transformation of data into valuable services, to compare digital vehicle services and to understand and explain the data-related challenges associated with them in a second step. In a third step, we apply the developed VDVC and use it to finally classify current digital vehicle services offered by four selected start-ups and five car manufacturers.

After this introduction and a description of our motivation in Section 1, we continue with the relevance of (big) data from both a general point of view and a vehicle-specific perspective in Section 2. In Section 3, we describe how vehicle data are turned into digital vehicle services, introducing the vehicle data value chain as the underlying process of value generation. We then apply this vehicle data value chain to visualize and compare the digital product innovations by selected start-ups (Automatic, Dash, Vinli, Zendrive) and car manufacturers (BMW, Honda, Mercedes, Porsche, Opel) in Subsection 3.3, before we use the VDVC to analyze the digital mobility service MoveBW in detail in Subsection 3.4. Finally, in Section 4, we conclude the paper and provide an outlook on various current activities including standardization and other activities of the European Commission and car manufacturers and the ongoing research project AEGIS, which aims to ease data fusion and the linking of data artifacts from multiple data sources.

2 FROM DATA TO BIG VEHICLE DATA

2.1 Data: One Aspect of Digitalization

More than a decade ago, Tim O’Reilly formulated his extensively cited principles of the Web 2.0 (O’Reilly, 2005) including one principle about the emerging value of data according to which “data is the next intel inside”. Since then, the hype on how to generate added value from all kinds of available data has been building. Data is the new buzzword. A book by Mayer-Schoenberger and Cukier (2013) on how Big Data is changing our world has become an international bestseller and been cited by researchers more than 2964 times according to Google Scholar. Big Data has received considerable attention from multiple disciplines, including information systems research (Abbasi et al., 2016) and database management (Batini et al., 2015), to mention two of them.

The volume of data is growing exponentially. It is expected that there will be more than 16 zettabytes (16 Trillion GB) of useful data by 2020 (Turner et al., 2014). It is just a logical consequence that data generation, data analysis, data usage – and related new business models – have found their way into all areas of life. Homes are increasingly equipped with smart meters, a replacement for mechanic measurement of electricity usage, enabling the emergence of digital services to assist home monitoring and to optimize electricity usage. Smartwatches can track the wearer's behavioral data and calculate periodic statistics such as daily, weekly, or monthly walking distances including burned calories per day, week, or month. Many people use their smartphones when exercising to gather information on their workout.

Smartphone apps such as Runtastic (2017a) and Strava (2017) help to monitor how and where people run or cycle, automatically calculating route, pace and periodic statistics including mean speed, time per kilometer, and calories burned. These apps even allow sharing the aggregated data via social networks, thus enabling benchmarking with peers and increasing the joy of exercise. The pattern of collecting, analyzing, and sharing data constitutes the baseline for individual improvements. Instantly calculated and visualized behavioral statistics are easy to compare or share with peers on social media. The collected information per se is not new to these communities. For instance, experienced runners started comparing their real and average time per kilometer using stopwatches a long time ago. However, the simplicity of digital services and the fact that many friends on social media regularly post about their exercising routine has motivated a whole digital generation to track themselves, as 210 million Runtastic app downloads demonstrate (Runtastic, 2017b). 30 million app sessions per month in Europe produce a reasonable amount of big movement data, which is sufficient for performing representative data analyses and attracts various stakeholders including Adidas.

To summarize, digitalization has greatly simplified data collection and analysis methods which used to be too complex and/or only available to experts. Hence, more and more people are joining the self-tracking movement and, in turn, produce more and more data which can be exploited using novel digital services.

2.2 The Big Data Value Chain

The internet age has spawned far more data on anything than any other technical or organizational innovation. Big Data refers to the current conglomerate of newly developed methods and information technologies to capture, store and analyze large and expandable volumes of differently structured data. In a definition by Demchenko et al. (2013), the defining properties of Big Data are Volume, Velocity, Variety, Value and Veracity, as shown in Figure 1. Exploiting the new flows of data can even improve the performance of companies, if the decision-making culture is appropriate (McAfee and Brynolfsson, 2012).

Big Data and intelligent things seem to have an intimate relationship. While in the Web 2.0 era data was mainly generated by humans sharing user-generated content on portals including YouTube, Wikipedia, or Facebook, the Internet of Things has led to new patterns of data generation driven by machines. Smart, connected objects equipped with all kinds of sensors have now taken over this task (Porter and Heppelmann, 2014 and 2015). The Quantified Self phenomenon is making use of these data generated by things (Swan, 2009 and 2015). Quantified Self refers to the intention to collect any data about the self that can be tracked, including biological, physical, behavioral, and environmental information. Making use of these data to establish applications and services has become a major creator of value. This value is created through

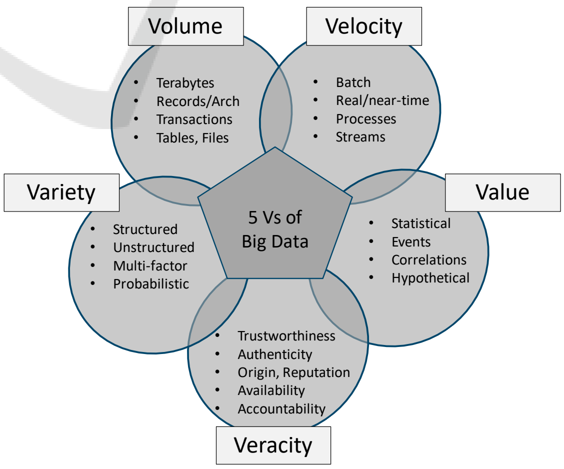

Figure 1: The 5 Vs of Big Data (Demchenko et al., 2013).

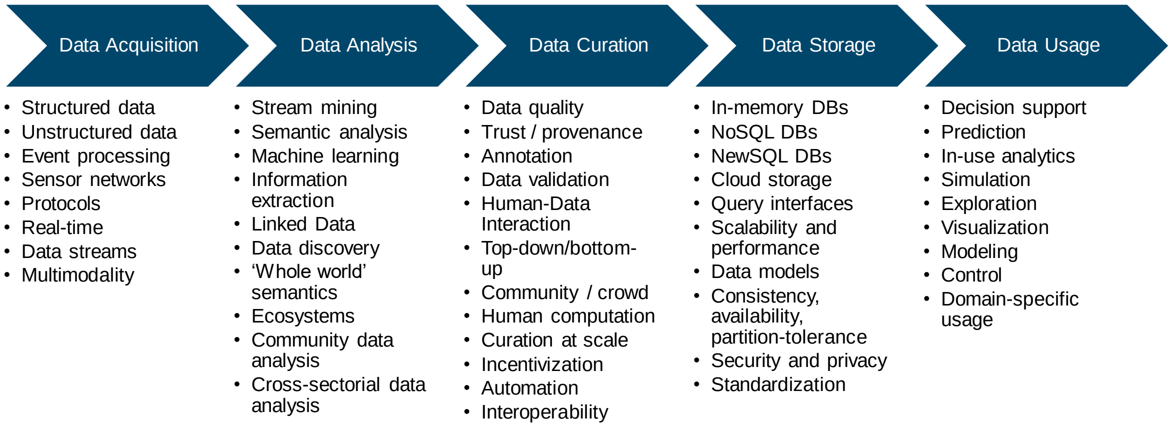

Figure 2: The Big Data Value Chain of Curry et al. (2014) / Curry (2016).

multiple activities which are chained together, while the value of the output is steadily increasing.

The concept of a value chain was originally introduced by Porter to describe a series of activities of a company to create and build value (Porter and Millar, 1985). This value chain concept can also be applied to the data domain to describe activities ranging from data generation to the usage of data in data-driven services for the customer. Data value chains are a model to describe data flows as a series of steps, each of them transforming the value of data. The concept of data value chains has already been used to describe the value of Linked Data (Latif et al., 2009) as well as of Big Data by Curry et al. (2014) as illustrated in Figure 2. The Big Data Value Chain mentions several steps of Big Data transformation in the process of generating the data-driven result with the maximum business value.

2.3 Big Data in the Context of Vehicles

Decades ago, vehicles were merely equipped with mechanical components such as mechanic handbrakes. However, electrification and comfort requirements continuously led to an electrically operated handbrake. The handbrake status (applied or released) and its process status (handbrake is applying/releasing) can be captured and used as input for vehicle safety checks and other features. An applied handbrake will automatically be released if the driver starts driving to prevent damage. The data generated through all these vehicle functions can be captured and used within other scenarios, e.g. to create statistics on how often a window is opened/closed or how often somebody is wedged in.

Many vehicle sensors are currently only used to offer functionality and/or to increase comfort and safety. As sensors and car features may widely differ from manufacturer to manufacturer and even per car variant, there is not only one single truth about how much data is effectively generated by a modern vehicle today. For instance, the participants from the EU project Automat (2017 and 2018) state that about 4000 CAN bus signals (one signal could be one measurement value) per second create up to 1 GB of data per CAN bus (without mentioning a sample rate). According to Pillmann et al. (2017), there are "usually 4-12 CAN busses in one car" (with varying amounts of input signals).

Considering the current hype around bringing highly automated driving into practice, several camera, radar and LiDAR (light detection and ranging) systems are additionally implemented within vehicles to capture each angle of the vehicle's environment. Autonomous vehicles are forced to exchange information with other vehicles (V2V) and with the infrastructure (V2I), which will boost the amount of available vehicle data enormously in the future. Considering different countries and different patterns of individual driving and mobility behavior, bringing highly automated driving into practice can be seen as a grand digitalization challenge.

However, while only some of these data can be exploited for digital vehicle services (e.g. because the sampling rate is too high or because some values are simply not relevant) and while only a portion of these data will be made accessible due to safety reasons (EU, 2013), the remainder of accessible sensor data from modern vehicles will most likely be sufficient to design and develop a reasonable number of novel digital vehicle services for various stakeholder groups, including individual drivers, various organizational customers, government authorities, and the automotive industry (Kaiser et al., 2017). To sum up, modern vehicles already constitute big vehicle data generators.

3 GENERATING BUSINESS VALUE: FROM VEHICLE DATA TO DIGITAL VEHICLE SERVICES

3.1 Generating Business Value by Leveraging the Self-tracking Trend

Many digital natives enjoy generating data anytime and anywhere using mobile devices including smartphones and smart watches. Increasing the knowledge about oneself and eventually enabling new discoveries while performing physical activities including running or cycling has turned into a business-relevant phenomenon. The behavior of turning collected data about oneself into actionable knowledge and insight which is valuable for other stakeholders, too, has been termed Quantified Self. Interestingly, the quantified self phenomenon has recently been successfully transferred to the automotive industry by US-based start-ups. In this sense and quite analogously, Quantified Vehicles (Stocker et al., 2017) imply a successful transformation of data from different kinds of sensors related to the vehicle (in-vehicle sensors, smartphone and wearable sensors used by the driver) into actionable knowledge, e.g. on the behavior of the vehicle. This way, they generate value for different kinds of stakeholders that are part of digital vehicle data service ecosystems such as insurance or fleet management providers, finally resulting in novel digital vehicle services in various domains (Kaiser et al., 2018b; Kaiser et al., 2019).

The pattern of self-tracking using consumer devices, as portrayed by the Runtastic example, can be easily transferred to vehicles: By default, vehicles gather a plethora of vehicle operation data through sensors and control units safeguarding a vehicle's functionality. However, these vehicle Big Data could be used to enable a series of apps and services. In the case of Runtastic, the combination of the company and the high volume of generated data, i.e. knowledge on where, how and how often users engage in physical activity such as running, was considered worth €220 million by the Adidas Group, which acquired Runtastic in 2015 (Runtastic, 2015).

The market value for vehicle data is considered to be even higher due to the importance of vehicles in first world countries. A number of US-based ICT start-ups seized this opportunity, now offering smartphone and web applications providing insights into vehicle-generated data, after they received up to €25 million of funding from investors (Stocker et al., 2017). Interestingly, while some car manufacturers and suppliers (e.g. Magna International, Continental ITS, and BMW i Ventures) are among the investors, forming strategic partnerships with start-ups, others participate in research projects and try to keep data-related business in their own area of influence. This holds for Volkswagen, for example, which coordinates the EU project *Automat* to develop a marketplace for vehicle lifecycle data (Stocker and Kaiser, 2016). Furthermore, recent reports from the German automotive industry association (VDA) suggest that car manufacturers "have to hold a stronger position in the future and may limit the capabilities of third parties to freely access car data." To summarize, the potential of vehicle data seems to be such that it has become a battle worth fighting (Kaiser et al., 2017). But how can vehicle data actually generate value?

3.2 The Vehicle Data Value Chain

In order to provide a structure and a frame of reference allowing to systematically describe the transformation of data into valuable services, to compare digital vehicle services and to understand and explain the data-related challenges associated with them, a value chain for vehicle data can be used. In this regard, we propose the Vehicle Data Value Chain (VDVC) as a lightweight model. We derived the VDVC from the Big Data Value Chain (Curry et al., 2016, illustrated in Figure 2). We adapted Curry's value chain regarding the name, number and order of stages to reflect our experiences from research projects in the automotive domain. The stage of (Vehicle) Data Generation was added as a separate stage to explicitly reflect the origin of the data (e.g. in-vehicle or related sensors). The stage (Vehicle) Data Acquisition corresponds to Curry's Data Acquisition. Moreover, we have changed the order of Curry's stages of analysis and curation since we interpret the terminology differently. For example, Curry seems to include normalization procedures implicitly within machine learning in the stage of Data Analysis, whereas we consider this as an important separate pre-processing step which correlates with Curry's stage of Data Curation. Hence, we have re-named Curry's stage of Data Curation *(Vehicle) Data Pre-processing*, which is followed by the stages *(Vehicle) Data Analysis*, *(Vehicle) Data Storage*, and *(Vehicle) Data Usage* (see Figure 3).

(Vehicle) Data Generation summarizes any sensors which can capture data directly (throttle pedal position) or indirectly (road surface condition). In the

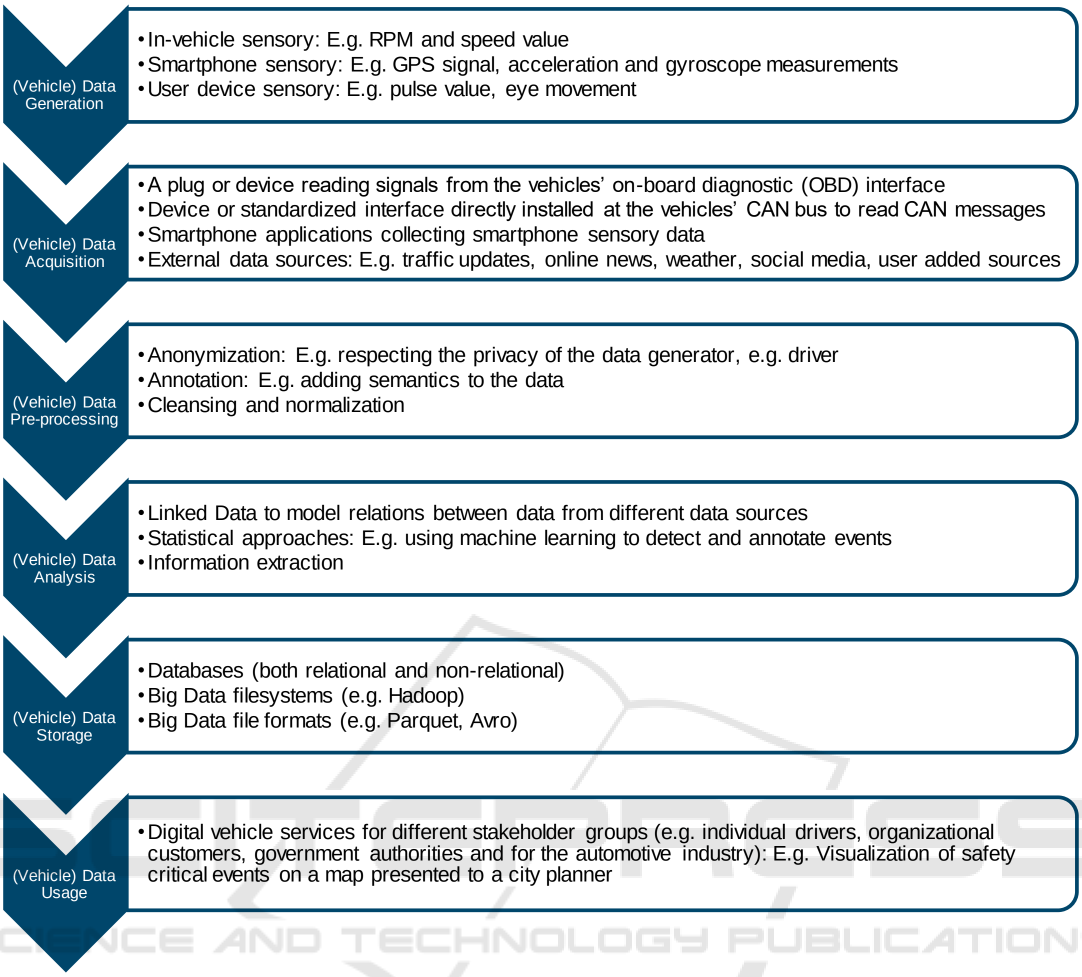

Figure 3: The Vehicle Data Value Chain derived from Curry (2016) and based on Kaiser et al. (2018).

case of direct influence, we mainly see three data sources: In-vehicle sensors, smartphone sensors and individual user device sensors (e.g. a pulse transmitter belt). An indirectly influencing data source can be literally any relevant data source, for instance a road operator camera to indicate traffic flow. This process step is not included in the Big Data process described in Section 2.3, however, it is essential for the vehicle data value chain, as the data origin indicates the reliability and the influence type (direct, indirect).

(Vehicle) Data Acquisition is the process of gathering the generated data. In-vehicle sensor data per se is not directly accessible, as it is captured with the purpose of safeguarding a vehicle's functionality and therefore only shared between the various electronic control units via one of the vehicle's CAN buses. However, a filtered amount of these sensor data is already accessible via the On-board diagnostic (OBD) interface (Turker and Kutlu, 2015), which is intended to be used by service staff to read generated error messages. It is however possible to develop plug-in devices with internet connection, to effectively use the OBD-port as a sensor data source. There are already some professional solutions with data acquisition devices installed in the vehicle, which directly read signals from the CAN bus in an unfiltered way. To meet the requirements of the EU Directive 2010/40/EU inter alia on the costless provision of universal, road safety-related minimum traffic information (EU, 2013), a standardized interface would be feasible sooner or later. Data from smartphones is acquired by using specific applications, which are capable of gathering and transmitting data. In the case of external data sources restricted to sources accessible via the Internet, the main issue are the different availability and quality levels of the data. For example, APIs commonly limit the number of requests allowed per time interval, meaning that the acquisition process must be adapted to respect these thresholds. Gathered data is stored for further processing; the chosen storage and format heavily depend on the following processing steps.

(Vehicle) Data Pre-processing describes any anonymization, annotation, cleansing and normalization activities before any data analysis is conducted. Sensor values may include private user information or may be erroneous, different sensors may have their own sampling frequency and so on. Data quality highly influences service quality. For instance, if the GNSS signal accuracy is low, a trip may not be linked to the correct road and may lead to false conclusions.

(Vehicle) Data Analysis with the purpose of extracting useful hidden information involves linking data from different data sources, exploring data, performing statistical analyses, using machine learning algorithms, and, if needed, detecting events, etc. For instance, weather data can be linked with the vehicle speed on a certain road to detect if the driver drives differently when the road is wet or icy.

(Vehicle) Data Storage "is the persistence and management of data in a scalable way that satisfies the needs of applications that require fast access to the data" (Curry, 2016). In the case of vehicle sensor data, persistent storage is usually achieved by using a combination of classic relational databases (for meta-data), Big Data file systems (for raw input data) and so called "time series databases", which allow fast analyses on the stored contents.

(Vehicle) Data Usage covers all ways of user or software interaction with the collected data and any conclusions derived from it in the above-mentioned process. The accessed data could either be regarded as the end result of the process, in which case it will be presented more or less directly to end users, or it could serve as input for further processing steps, forming a circular path in the processing chain.

3.3 Applying the VDVC to Describe Digital Vehicle Services Offered by US Start-ups and Prominent Car Manufacturers

The Vehicle Data Value Chain (VDVC) introduced in the previous section describes a set of activities to create value out of vehicle data. Consequently, a "vehicle data to service"-process can be derived from the above mentioned VDVC. In this section, we aim to apply the VDVC as a lightweight model to characterize selected public digital vehicle services offered by four start-ups and five car manufacturers. The stages of (Vehicle) Data Curation to (Vehicle) Data Storage of the value chain are part of the respective digital vehicle service providers' business asset and are therefore not publicly available. In addition, not all digital vehicle service providers can be expected to publish a full list of third-party stakeholders which have access to the vehicle data acquired. However, in a second step we add a detailed description of a single service called MoveBW, which was co-developed by one of the authors, so that we can give insights into the value chain of this service.

Digital vehicle service providers we chose are presented in Table 1. This table focuses on services for individual drivers and explicitly observes the following three process steps: (i) (vehicle) data generation, (ii) (vehicle) data acquisition and (iii) (vehicle) data usage. (Vehicle) data usage is structured using four categories: (a) Recommendation specifies all digital vehicle services that give recommendations to the user, e.g. how to improve fuel efficiency; (b) Vehicle status & trip statistics lists services which represent the status of the vehicle (e.g. remaining fuel) and statistics from recent trips (e.g. a score representing the driver's cautiousness); (c) Access to vehicle features gives a list of services which enable vehicle features to be accessed using a smartphone application (e.g. controlling the air conditioning); (d) Other contains all services which go beyond the aforementioned categories.

The resulting table shows that the various digital vehicle services provided by start-ups and car manufacturers (termed OEM for Original Equipment Manufacturer) vary in terms of data generation, data acquisition and data usage. For instance, start-ups access in-vehicle data mainly by exploiting the OBD interface, except for Zendrive, which relies on smartphone sensors only. The OBD plug-in devices used by the start-ups differ, as they have additional sensors built in to capture additional data and hardware to establish UMTS/WIFI connections for transmitting data to the storage. The only exception is Honda, which also uses the OBD plug solution. Car manufacturers use the advantage they have as the vehicle developer and rely on an integrated CAN bus device that can capture vehicle data from far more sensors than OBD-based devices. It is surprising that the offered digital vehicle services somehow resemble one another.

Due to limited information access, the applicability of the VDVC for US tech start-ups and prominent car manufacturers has been shown using the steps Data Generation, Acquisition, and Usage only. However, in the following section, we analyze one mobility service where we have insights into the full process using each step of the VDVC.

Table 1: A digital vehicle service overview focusing on (Vehicle) Data Generation, Acquisition and Usage.

Service Provider	Service Purpose	Data Generation	Data Acquisition	Data Usage for drivers including business customers
Automatic (Start-up)	Driving statistics to infer behavior	In-vehicle sensors & device sensors	OBD device	*Vehicle status & trip statistics* (driving behavior insights using a score; event detection e.g. hard brakes or speeding; location & trip tracking; business tagging; fill up logging; vehicle error messages; crash alert) *Other*: IFTTT (IF This Then That)
dash (Start-up)	Driving statistics to infer behavior; Gamification	In-vehicle sensors & device sensors	OBD device	*Recommendation* (improve fuel efficiency; ranked refueling places) *Vehicle status & trip statistics* (driving behavior insights using a score; location & trip tracking; fuel quantity; live speed, rpm, engine load, etc.; vehicle error messages) *Other*: gamification (rewards, leaderboard)
Vinli (Start-up)	Ecosystem with 40 Apps: individual purposes	In-vehicle sensors & device sensors	OBD device	Some known services: Amazon 'Alexa': trip statistic integration when asked for ("Where is my car?"); IFTTT (IF This Then That) programmable functionality; 'Home Connect': e.g. close garage door when leaving with passenger car; etc.
Zendrive (Start-up)	Gamification, fleet mgmt.	Smart-phone sensors	Smart-phone app	*Recommendation* (coach safe driving) *Vehicle status & trip statistics* (driving behavior insights using scores, e.g. Caution Score; location & trip tracking)
BMW (i) Connected Drive (OEM)	Personal mobility assistant	In-vehicle sensors & external sources	CAN bus device	*Recommendation* (Navigation based on traffic status; parking place recommend.) *Vehicle status & trip statistics* (location & trip tracking; emergency call; fuel quantity) *Remote access to vehicle features* (unlocking; honking; air conditioning)
Honda (OEM)	Driving statistics to infer behavior	In-vehicle sensors & device sensors	OBD device	*Vehicle status & trip statistics* (location & trip tracking even in car parks; emergency call; fuel quantity; vehicle error messages) *Other*: geo-fence alarms (leaves area)
Mercedes me (OEM)	Personal mobility assistant	In-vehicle sensors & external sources	CAN bus device	*Recommendation* (Navigation based on traffic status; fleet mgmt.) *Vehicle status & trip statistics* (location & trip tracking; emergency call; trip logging; fleet mgmt.) *Remote access to vehicle features* (remote parking; unlocking; air conditioning)
Opel OnStar (OEM)	Personal mobility assistant	In-vehicle sensors & external sources	CAN bus device	*Vehicle status & trip statistics* (location & trip tracking; emergency call; fuel quantity, tire pressure, etc.; vehicle error messages) *Remote access to vehicle features* (unlocking; honking) *Other*: Privacy options
Porsche Connect (OEM)	Personal mobility assistant	In-vehicle sensors & external sources	CAN bus device	*Recommendation* (Navigation based on traffic status, including hints for frequently used routes if navigation is turned off; parking place recommend.) *Vehicle status & trip statistics* (location & trip tracking; emergency call; fuel quantity) *Remote access to vehicle features* (Smartphone and vehicle navigation are connected; unlocking; honking) *Other*: smart home features (close garage door when leaving with passenger car)

3.4 Applying the VDVC to Describe MoveBW, a Digital Vehicle Service

MoveBW is a regional, intermodal mobility service offered by a European industry consortium and which is currently being developed to increase the compliance rate of transport users (e.g. the percentage of people using a park and ride option) with regard to the current transport strategy of the region. The strategy mainly aims at meeting air quality targets and reducing traffic jams all over the federal province of Baden-Württemberg (Germany), including its provincial capital Stuttgart.

Stuttgart is geographically located in a valley basin, which has a negative effect on air pollution with particulate matter. Thus, the city of Stuttgart continuously develops transport strategies to better comply with air quality regulations. In the past, these strategies were communicated to the public using radio traffic messages or electric traffic signs only. However, the compliance rate and thus success were comparably low. The new MoveBW mobility service smartphone application aims to increase the compliance rate, especially that of visitors new to the region. It does so by including easy-to-use routing functionalities which are connected to rewards: Bonus points are granted if a user follows the recommended route. Collected bonus points can later be exchanged for immaterial or monetary values.

Users of the MoveBW smartphone application can plan their trips in advance using the intermodal journey planner. They can pick their preferred combination of transport modes from different options suggested to them. Additional information is displayed, not only showing travel time, but also eco-friendliness, travel costs and incentives gained (e.g. public transport vouchers and CO2 savings). Moreover, it is possible to directly book tickets for the different modes of transport included in their preferred journey and yet to receive only one bill. In this way, transport services such as public transportation, car sharing, bike sharing, and parking space management are integrated conveniently, encouraging users to make efficient use of all modes

Table 2: A digital vehicle service overview focusing on (Vehicle) Data Generation, Acquisition and Usage.

VDVC step	Description of MoveBW-Service
Data Generation	Various sensor data and basic reference data is considered, e.g. - floating car data: average mean travel time per road segment based on anonymized GNSS data of vehicles, - stationary traffic measurement: rate of flow for single measurement locations, - public transport: schedule and sometimes occupancy rate, - car park interfaces: occupancy rate, - park & ride interfaces: occupancy rate, - air quality measurement units: air quality measurements and forecast (includes weather forecast);
Data Acquisition	Querying the web APIs from the various data sources. Additionally, the smartphone App which is used in Data Usage provides GNSS information, as this is used for on-trip routing and to detect which means of transport the user actually uses to be able to reward if the recommended option is used.
Data Pre-processing	Annotation, normalization and semantic extraction of data. Transformation of data to meet a common reference basis (in this case a public transport grid, no typical geo-coordinates). Furthermore, GNSS data from the smartphone App is anonymized (start- and end-trajectories are truncated). In this step the data is hosted in a distributed database system (e.g. PostgreSQL cluster)
Data Analysis	A dynamic routing algorithm which also takes the provided intermodal transport strategy, CO2 savings, and personal preferences into account. A self-developed algorithm which utilizes pgRouting (an open source project to extend PostGIS/PostgreSQL to provide geospatial routing functionality) and the popular Dijkstra algorithm (to find the shortest path between nodes) Thus, the algorithm provides routing recommendations (weightings for routes)
Data Storage	A distributed database system, e.g. a PostgreSQL cluster
Data Usage	The MoveBW App currently being developed should help the commuter to choose a mode of transport and guides the commuter to the selected destination in compliance with environmentally-oriented traffic management strategies.

of transport. The application also provides on-trip navigation and information on traffic obstructions such as construction works or accidents.

The MoveBW services are currently monitored and evaluated in an extensive trial phase. Based on the findings, both the digital service and traffic control strategies will be revised, aiming to maximize favored effects on the individual mobility behaviors of traffic participants, for example by applying different strategies for daily commuters and visitors. The smartphone application is planned to be released in the first quarter of 2019. Mock-ups of the current design are shown in Figure 4.

Figure 4: The MoveBW smartphone application provides functions for intermodal journey planning, traffic information, ticketing and on-trip navigation. (Source: https://www.altoros.com/blog/mobile-devices-are-propelling-industrial-iot-scenarios/).

Taking a wide range of data sources into account for the intermodal routing algorithms in the MoveBW App, data management becomes a challenge. The Vehicle Data Value Chain introduced in Section 3 helps to provide a clearer view. Its application to the underlying data transformation process, from Data Generation to Data Usage, is shown in Table 2.

4 CONCLUSION AND OUTLOOK

Digitalization has become an important driver of innovation in the automotive industry, enabling a plethora of digital vehicle services. We have presented a review of available digital vehicle services offered by startups and car manufacturers and described them applying the Vehicle Data Value Chain (VDVC). Many of them were originally motivated by the self-tracking phenomenon, which has been transferred to the vehicle domain, constituting quantified vehicles.

As an outlook, it should be mentioned that digital vehicle services and the required technological infrastructure to facilitate data acquisition, pre-processing, analysis and storage, are currently a hot topic in the automotive domain. There are already initial ideas using blockchain technology and brokers to make data sharing transparent and secure, as described in Kaiser et. al (2018a). Yet, while some car manufacturers invest in start-ups, others limit access to data via the OBD interface, arguing that they are not suitable for digital vehicle services (VDA, 2017; ACEA, 2016). In contrast, the European Automobile Manufacturers Association ACEA promotes car data sharing (ACEA, 2017).

One reason for activities in this area is the Commission Delegated Regulation (EU) No 886/2013 (regarding Directive 2010/40/EU on Intelligent Transport Systems – ITS) published by the European Commission. It regulates the costless provision of universal, road safety-related minimum traffic information to users and requests car manufacturers to provide safety-relevant data to the public by making it accessible through national contact points (EU, 2013).

Furthermore, the International Organisation for Standardisation (ISO, 2017) has set up a standardization work group titled *ISO/TC 22/SC 31/WG 6 Extended Vehicle/Remote diagnostics* (ISO 2018) to inter alia define access, content, control and security mechanisms for the provision of vehicle data for web services (VDA, 2017).

In parallel, a joint initiative of 17 EU Member States and road operators is launching a solution for C-ITS services in order to transmit information from infrastructure (e.g. road side units) to the vehicle cockpit, e.g. to inform about slow or stationary vehicle(s), traffic jams ahead, weather conditions, speed limits, etc. (C-ROADS, 2017).

Additionally, current EU-funded projects such as the AEGIS Big Data project or EVOLVE are developing solutions to ease the integration and fusion of multiple data sources for the purpose of service and business development using Linked Data (AEGIS, 2017; EVOLVE, 2019; Latif et al., 2009). “Linked data is a lightweight practice for exposing and connecting pieces of data, information, or knowledge using basic web standards. It promises to open up siloed data ownership and is already an enabler of open data and data sharing” (Rusitschka and Curry, 2016).

To conclude, we expect the market of digital vehicle services to grow tremendously in the future, as the combination of vehicle data with data from external sources (e.g. weather data, traffic data, open data) will enable new scenarios for digital vehicle services.

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