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MOBILITY REINVENTED: KEY DISRUPTIVE TRENDS CHANGING THE MOBILITY OF THE FUTURE

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1 Introduction

1.1 Relevance of the topic and problem statement

The wider mobility space has always been a fast-changing and developing industry (Abdelkafi, Makhotin, and Posselt 2013). In recent years, a fundamental technological, social, and economic transformation took place, significantly impacting the way people and goods will be transported in the future (KPMG 2019). The underlying driving forces of this transformation are the demand for environmentally sustainable transportation based on a global consensus to reduce carbon emissions, a growing digitalization within the mobility space due to technological advancements and changing consumer needs emphasising flexible and personalised mobility services (Accenture 2020). This transformation has led to the emergence of new mobility solutions and players in the space (Riasanow, Galic, and Böhm 2017) and a challenge for traditional automotive manufacturers to adapt their mobility solutions (Arthur D. Little 2018). Much of academic and professional literature on mobility focuses on four key trends which have the potential to disrupt the mobility space fundamentally (Krause et al. 2020; Munoz et al. 2021; McKinsey & Company 2019b; KPMG 2019; Accenture 2020): *(1) autonomous driving, (2) connectivity, (3) electrification,* and *(4) mobility as a service*, in this work referred to as ACEM trends. These four key trends, if successfully established, will shape the mobility of the future.

1.2 Objective of the work and outline

This work has the objective to give an overview on the four key disruptive trends, to identify and summarise potential benefits as well as major challenges and introduce deciding factors on their way to become industry standard within the mobility space. Within the literature review, first, a general background on the mobility industry is provided. Secondly, definitions of the ACEM trends are given and potential benefits and challenges are presented. Afterward, key requirements for the establishment of the four trends as industry standards are explained. Next,

this work will present two main analyses focussed on individual topics. Hereby, the third section dives into one of the key trends, electrification, and focuses on electric vehicle (EV) battery recycling which is key for a successful electrification strategy. Major challenges and potential solutions for battery recycling from an automotive manufacturer's perspective are investigated. Furthermore, building on the benefits and opportunities presented by the ACEM, section 4 highlights key elements for the creation of user experiences in mobility and analyses the role of user experiences as a potential competitive differentiator. Finally, in the conclusion, the findings are brought together and potential for further research is stated.

2 Literature review

This chapter comprises an academic literature review with a narrow focus on the theoretical background and understanding of the mobility industry. Building on this theoretical understanding, the identified key disruptive trends in the space of future mobility are introduced in 2.2. The following chapter 2.3 is dedicated to the ongoing development within the key disruptive trends and elaborates which factors are required for those to become an industry-standard in the mobility space.

The literature review "concisely summarizes the findings or claims that have emerged from prior research efforts on a subject" (Knopf 2006, 127). In recent years, research and literature have increasingly addressed the identified key disruptive trends within the mobility space. The literature review provides the necessary context within the existing literature and sets the stage for this work and future research (Rowley and Slack 2004). Articles in academic and research journals form the core of the literature review due to a more solid theoretical foundation and more critical treatment of concepts and models (Rowley and Slack 2004). Nevertheless, especially with the topic of disruptive trends in the rapidly evolving future of mobility, recent studies and professional literature must also be included to demonstrate an in-depth understanding (Denney and Tewksbury 2013).

2.1 Theoretical background on the mobility industry

Around the mobility industry, related terms such as sustainable mobility and smart mobility have emerged in recent years. In this work, a broader understanding of the mobility industry is used to lay the foundation for the work. In general, mobility refers to how people and goods are moved (McKinsey & Company 2016). This includes public and private transport as well as the transportation of goods. Technological progress, innovations, the importance of sustainable and environmentally friendly solutions as well as changing behaviours are the drivers of an ever-evolving mobility industry (Wolff and Hakanen 2021). Consequently, market structures and the focus of technological innovation and business strategies are changing (McKinsey & Company 2017). With emerging mobility modes and services, new players are entering the market and redefining the value chain and value propositions of future mobility. Incumbents and emerging players are finding themselves competing in a more diverse and broadly imagined mobility space. The mobility industry extends far beyond the more traditional players in the automotive industry or the public and private transportation sector (Fournier 2016). It also includes increasingly important technology and communication companies that offer their own mobility services (Peters Steven, Chun Jung-Hoon, and Lanza Gisela 2016). Through greater customer-centricity, the players are trying to fulfil the increasing mobility demands and are challenging the approach to serve the customers in the best possible way. Furthermore, new raw materials and sustainable components are becoming part of the value chain (Fournier 2016; McKinsey & Company 2017). The transformation of the value chain described by Fournier (2016) can be found in Appendix 1. However, the changing mobility landscape does not only affect how people and goods will be transported – it also leads to new opportunities and predicted growth of the mobility market. With a predicted global value of the mobility ecosystem of US$ 1 trillion US dollars in 2030, the mobility industry remains of great economic relevance (KPMG 2019).

2.2 Key disruptive trends shaping the mobility of the future

Identifying trends is crucial to anticipate future mobility behaviours and to predict how technological developments impact the businesses of existing and emerging mobility players. Academic literature has identified several trends directly or indirectly impacting the mobility industry such as blockchain, 5G or robotic process automation (RPA) (Krasniqi and Hajrizi 2016; S. Chen et al. 2017; Sharma, Kumar, and Park 2019; Fraga-Lamas and Fernández-Caramés 2019; Rao and Prasad 2018). However, over the past years, particularly four disruptive trends have been discussed as key trends shaping the future of mobility: *autonomous driving, electrification, connectivity,* and *mobility as a service (MaaS),* abbreviated in this work as ACEM trends. In academic and professional literature, the acronym used for the four disruptive trends often is referred to as ACES, meaning automation, connectivity, electrification and sharing (Krause et al. 2020; Munoz et al. 2021; McKinsey & Company 2019b). Sharing or shared mobility hereby generally refers to the access of shared mobility solutions, whereas MaaS refers to bundling shared mobility solutions in one single platform, which will be further elaborated in section 2.2.4 (MaaS Alliance 2017; Machado et al. 2018; Hietanen 2014; Goulding and Kamargianni 2018). In pursuing and developing key trends, incumbent but also new players face a challenge that requires capital-intensive efforts. However, these efforts and investments are necessary to remain competitive in the future and to secure market share (Roland Berger 2019). The number of patents and investments made in recent years underlines the continuing relevance of those key disruptive trends. McKinsey elaborated that since 2010 over 60,000 patents in the fields of the ACEM trends have been filed. Nearly $330 billion have been invested into more than 2,000 mobility companies focused on autonomous driving, connectivity, electrification, and mobility as a service (McKinsey & Company 2021a). The following sections 2.2.1 to 2.2.4 aim to provide relevant background and a general

understanding of respectively all those four key disruptive trends and introduce potential benefits as well as challenges to the mobility industry.

2.2.1 Autonomous driving

The first key disruptive trend within the mobility industry is *autonomous driving* leading to autonomous vehicles (AVs). There is no consistent definition of AVs in academic literature as the degree of automation in vehicles can vary. While McKinsey and Company (McKinsey & Company 2014) already mention driving assisting features as defining for autonomous vehicles, Fagnant and Kockelman (2015) describe AVs as vehicles "that can drive themselves on existing roads and can navigate many types of roadways and environmental contexts with almost no direct human input" (167). Early experiments in the 1980s and 1990s were already working on the technological feasibility of cars that autonomously control their movements in complex environments (Campbell et al. 2010). Even nowadays, work is still being done on the technological implementation of autonomous driving. To make autonomous driving possible, several real-time systems have to work together. Adequate vehicle equipment including the necessary sensors and computer hardware must be available, and a functioning software infrastructure must be developed (Levinson et al. 2011). According to the SAE, the most cited source within autonomous driving literature, six levels of driving automation can be identified which are illustrated in the table below (SAE International 2021).

0	1	2	3	4	5
Zero Automation	Little Automation	Medium Automation	High Automation	Very High Automation	Full Automation
Driver controls vehicle completely. No automated assistance.	Driver fully controls vehicle with little assistance features including braking or accelerating assistance.	Driver partially controls but fully monitors vehicle. Combined assistance features include steering and acceleration support.	Driver controls vehicle only when assistance features request. Automated assistance features control vehicle under certain conditions.	Driver has option but no obligation to control vehicle. The vehicle carries out all driving actions under set conditions.	Driver potentially has option to control vehicle. The vehicle carries out all driving actions under all conditions.

***Table 1**: 6 levels of automation (author's illustration based on* SAE International 2021*)*

Most academic research on autonomous driving predicts that this technology will fundamentally change mobility in the upcoming years and several key advantages are mentioned (Kassens-Noor et al. 2020; Leonard, Mindell, and Stayton 2020; Faisal et al. 2019). First, Rojas-Rueda et al. (2020) argue that AVs will likely significantly reduce traffic-related accidents caused by human errors. It is estimated that about 1.3 million people die each year in or related to road traffic accidents, which is one of the major causes of death worldwide (WHO, 2021). 94% of these accidents are related directly to the driver such as distraction while driving, not adhering to speed regulations, or driving with imperfect vision (U.S. Department of Transportation 2018). AVs could play a major role in increasing road safety and saving lives (Rojas-Rueda et al. 2020). Furthermore, it is predicted to achieve several environmental benefits and emission reduction through an improved traffic flow as well as less fuel consumption through autonomous foresighted driving (Luettel, Himmelsbach, and Wuensche 2012). Lastly, several scholars have identified possible positive social aspects of autonomous driving such as the ability to reduce the level of stress (Rudin-Brown and Parker 2004) or increase productivity (Jamson et al. 2013) through reduced involvement or complete absence of the driver.

However, many scholars have also argued critically towards full automation of vehicles. Faisal et al. (2019) argue that legal, political, and urban planning administration is still far behind the technological advancement. For example, uncertainty around liability and insurance, which raises concerns. The authors further question the overall impact in the reduction of traffic accidents, as, despite the possible avoidance of driver errors, new issues such as software failures or factors outside of the autonomous system may occur (Faisal et al. 2019). Another argument that is pointed out is that very high vehicle costs are expected initially, and the risk of hacking can call security issues (Litman 2020). Moreover, when investigating purchase decisions for an AV, an ethical dilemma became apparent. Buyers would always favour an AV

that protects the passenger at all costs. In contrary to this, for others, buyers would appreciate a utilitarian AV, which sacrifices the passenger for the greater good (Bonnefon, Shariff, and Rahwan 2016). Lastly, before AVs will become fully standard on the streets, the vehicle infrastructure within cities needs to be fundamentally adapted which will take a considerable amount of time and investment (Shiwakoti, Stasinopoulos, and Fedele 2020).

2.2.2 Connectivity

The second key trend which is widely identified in academic literature to fundamentally transform the mobility industry is *connectivity* or *connected vehicles* (CV) (Lu et al. 2014; Guanetti, Kim, and Borrelli 2018; Lee and Park 2012). Several definitions of connectivity concerning mobility exist, describing the parties involved and the type of connection. Ha et al. (2020) refer to the Federal Communications Commission and define connectivity as "the capability of a vehicle to communicate to and from other systems (…) that are located outside of the vehicle, via various relatively short- and long-range connectivity technologies" (2). Connectivity can also be described as the implementation of the Internet of Things (IoT) within the mobility space, as IoT enables any object to transmit and receive data to achieve more efficiency (Xia et al. 2012). McKinsey & Company (2014) uses a broader definition and describes CVs as "vehicles that build on processed information between vehicles and their environments" (13). Different destinations such as vehicle-to-vehicle, vehicle-to-infrastructure and vehicle-to-cloud can be meant, which are connected through various short-range and long-range communication channels (Ha et al. 2020; Olia et al. 2016). Information can be exchanged with any stationary systems like traffic lights or other infrastructure, as well as any moving systems like other traffic participants including vehicles and pedestrians (Ha et al. 2020).

A lot of literature on connectivity in the mobility space focuses on the potential benefits that CVs might bring. The first and most significant advantage is an improvement in safety through driving assistance. The possibility of increasing the safety for the driver and passengers within

the vehicle and for the environment outside the vehicle has been extensively investigated in the literature (Goodall, Smith, and Park 2013; Lu et al. 2014). Many driver-assisting features already exist in today's vehicles such as blind-spot detection, active cruise control and collision warning systems. It is also said that driving assisting features are likely to become more standard in the future, continuously decreasing human error (McKinsey & Company 2014). Beyond that, CVs are expected to counteract the unpredictability of close vehicles by transmitting information, which would reduce the need for the driver to fully rely on their reaction speed, attention, and vision (Ha et al. 2020). The second major improvement through CVs is the increase of in-car content and services, which not only improves the driver's infotainment but also integrates personal devices such as smartphones more into the mobility journey (Heiden 2019; McKinsey & Company 2014). The third benefit identified is preventive maintenance or so-called vehicle relationship management through which vehicles could continuously be monitored and occurring damages can be identified early (McKinsey & Company 2014; Heiden 2019). An improved insurance offer can be seen as the fourth main benefit, as real-time data of vehicle usage can be analysed and thus insurance services can be improved (McKinsey & Company 2014). Additionally, besides these more driver-specific benefits, there are more general, system-related benefits such as optimized route planning or hazard warning through real-time information exchange between vehicles (Filipovska, Mahmassani, and Mittal 2019). Smaller benefits that are connected to the previously mentioned AVs could include harmonization of traffic and improved efficiency in traffic signal operation (Goodall, Smith, and Park 2013). More efficient routing with less congestion enabled by CVs leads to minimal stop-and-go conditions, resulting in lower emission levels which also demonstrates a positive environmental impact of CVs (Olia et al. 2016).

Despite all the suggested benefits, connectivity between vehicles may also lead to potential risks. One risk which has been discussed heavily within academic research is the potential of a

CVs being hacked (Vivek et al. 2019; Škorput et al. 2020; Li et al. 2018). The many technical systems that enable a CV to connect to another vehicle present a wide range of targets for hacking. Because vehicles are inherently fast and heavy, they can cause significant damage to passengers and the external environment if hacked with malicious intent.

2.2.3 Electrification

The third trend mentioned by academic literature is *electrification.* When having a closer look, electric vehicles (EVs) already have a longer history and attracted a significant degree of attention as early as the 1900s (Bansal 2005; Ajanovic 2015). In the past, interest in electric vehicles was often closely linked to gasoline price developments. In recent years, electric vehicles have become a key trend in the mobility sector, mainly due to environmental concerns (Rajashekara 1994). In 2019, the total transport sector emitted 8.2 gigatons of CO2 emissions and was, therefore, responsible for 24% of CO2 emissions from fuel combustion (IEA 2020). An ongoing societal change towards environmentally sustainable behaviour and accompanying policy requirements make a transition to more sustainable electric mobility inevitable.

The electrification of vehicles has established itself as the most promising environmentally friendly alternative to future mobility. This is since EV's energy transmission is based on a power grid instead of fuel. When electricity is provided through renewable energy sources, carbon emissions on a well-to-wheel basis are reduced and EVs become the most energy-efficient mobility solution in the long run (Fournier 2016; Bansal 2005). Furthermore, electric motors are less complex and require less maintenance (Bansal 2005). EVs are already transforming the industry which can be seen in their development of market growth. The registration of EVs has constantly increased and reached approximately 41% in the previous year resulting in 10 million EVs on the roads globally by the end of 2020 (IEA 2020). Sustainable mobility is the clear goal within the upcoming years and represents the main benefit of electrification.

However, there are also concerns and challenges which majorly focus on the vehicle range, vehicle cost, fast and easy charging, or the whole battery lifecycle management that affect successful electrification of mobility (Bansal 2005). These challenges mainly originate from the battery, which is identified as the biggest weakness of EVs and will be further investigated in Section 3 (Bansal 2005; Ajanovic 2015; Rajashekara 1994). Furthermore, for a successful transition from combustion to electric mobility, a change and major investments in knowledge and machinery are necessary (Casper and Sundin 2021). Additionally, with the growing numbers of EVs on the streets, the charging infrastructure must also be extended. EV charging infrastructure therefore still presents challenges such as being operated by several providers with different charging standards and processes (Zhimomi, Alam, and Malik 2021).

2.2.4 Mobility as a service

The fourth key disruptive trend is *mobility as a service*, short MaaS. As mentioned earlier, while there are several similar terms such as 'sharing' or 'shared mobility', this work focuses on the term MaaS (Krause et al. 2020; Shaheen, Cohen, and Zohdy 2016). The term has its origin in Finland where an early definition by Hietanen (2014) describes it as "a mobility distribution model in which a customer's major transportation needs are met over one interface and are offered by a service provider" (2). A broader definition from Sakai (2019) describes MaaS as all transportation modes different than private cars such as "railway, bus, on-demand transport and taxis" (207). A key focus in many definitions of MaaS within academic literature is the accumulation of mobility services into one single platform (Hietanen 2014; MaaS Alliance 2017; Kamargianni and Matyas 2017). Kamargianni and Matyas (2017) specifically emphasise the single platform approach when defining MaaS as "a user-centric intelligent mobility distribution model in which all mobility service provider's offerings are aggregated by a sole mobility provider, the MaaS provider, and supplied to user through a single digital platform" (4). On the one hand, from a user perspective, the convenience of having multiple mobility

services and options combined in one platform allows MaaS to present a clear alternative to owning a private car (Giesecke, Surakka, and Hakonen 2016). On the other hand, from a political and societal perspective, MaaS systems offer an opportunity for cities to decrease private car ownership and increase the use of public transport, which in turn brings environmental benefits (Goulding and Kamargianni 2018). Additionally, MaaS can further improve several factors within mobility for users such as accessibility, efficiency, coverage, flexibility, safety, and inclusion (Butler, Yigitcanlar, and Paz 2020). As more and more vehicles are shared, new opportunities to adapt the mobility infrastructure arise. Predictions exist that when more vehicles are shared, not only fewer parking spaces will be needed, but eventually, there will even be generally fewer vehicles on the road, as ownership will give way to the efficiency of sharing a vehicle (Duarte and Ratti 2018; Ross 2014).

However, fully integrated, and widely established MaaS systems are not yet commonly available in every city, which might relate to specific challenges. One such challenge is the necessity for MaaS systems to operate profitably and avoid solely relying on government subsidies (Butler, Yigitcanlar, and Paz 2020). Literature suggests that MaaS businesses, such as carsharing or micro-mobility services, are not yet profitable, even though providers already have millions of users on board (Lagadic, Verloes, and Louvet 2019; Kao, Matyas, and van den Heuvel 2020). MaaS offerings are aiming to build a large and growing customer base to benefit from network effects and to truly impact the mobility space. In recent years, new solutions and providers have entered the market, resulting in intense price competition and unstable market conditions while pursuing the path to profitability (Lagadic, Verloes, and Louvet 2019; Accenture 2020). Depending on the business models, further challenges are low asset utilization, labour intensiveness and insufficient use of technology (Accenture 2020). Finally, appropriate governmental regulation of private mobility services is a precondition for a coherent system of innovations and stable mobility offers in one platform. Machado et al.

(2018) describe this as “a breakeven point among administration, regulation, and control that enable disruptive innovations in urban mobility to be integrated into transportation systems” (15).

2.3 Requirements for key disruptive trends to become industry standard

Realising the potential of the AECM trends will play a major role in shaping the future of mobility. AECM trends vary in their progress toward becoming industry standards in mobility. The developments within the key disruptive trends are influenced by firstly already known and plannable factors and secondly by a certain degree of uncertainty. Therefore, experts from academic literature and industry have become more cautious about making accurate predictions when the trends will experience their breakthroughs. However, already today it is possible to identify main factors and milestones, which need to be achieved, to pave the way for AECM to establish itself in the mobility of the future. In this work, three main drivers were identified and will be discussed respectively in the following chapters: *technological advancements, acceptance among customers and users,* and *legal and political requirements.*

2.3.1 Technological advancements

Constantly innovations are developed, changing, and improving efficiency, sustainability, costs, or other factors within the mobility space (van den Heuvel, Kao, and Matyas 2020). When comparing the four AECM trends, different levels of technological advancement and therefore ‘readiness’ to be fully established within the mobility sector can be observed.

Regarding autonomous driving, there is still a long way ahead until fully autonomous level 5 vehicles dominate the streets worldwide. According to Litman (2020), an optimistic estimate is that Level 5 autonomous vehicles will be safe and reliable from a technology perspective in 2025. Nonetheless, time would then be needed for testing and regulatory approval. Currently, the most technologically advanced vehicles enable autonomous driving according to SAE levels 2 and 3. Level 4 technologies are in development stages, but significant technological

advancement and testing are required before AVs can operate reliable also under more challenging conditions such as urban traffic, snow, or limited connectivity (Litman 2020; Leonard, Mindell, and Stayton 2020). Leonard, Mindell, and Stayton (2020) support these predictions and estimate that it will take "more than a decade" (3) for fully AVs to become industry standards.

Autonomous driving and connectivity are in many ways technologically intertwined. Connectivity within the mobility space has a large potential to accelerate the development of autonomous driving, while this does not hold vice versa (Ha et al. 2020). Required technological advancements for widespread adoption of CVs are mainly related to a significant redesign of the architecture of communications networks to ensure the necessary connectivity and capacity for the various applications (Mahmood et al. 2016). Two major factors negatively affect the establishment of connectivity as industry standard. The first major factor is the little technological maturity of the unified connectivity platform Cellular Vehicle to Everything (C-V2X), which enables vehicles to communicate with other vehicles (vehicle-to-vehicle), the infrastructure such as traffic lights (vehicle-to-infrastructure), and pedestrians (vehicle-to-pedestrian). The second major factor is the absence of a general standard for data sharing between automobile manufacturers (Ha et al. 2020).

In terms of the electrification of vehicles, there has been significant technological progress in recent years regarding electric powertrains and batteries, with a focus on increasing the range and decreasing costs. While the establishment of EVs on the world's roads has been ongoing over the past years and the sales number for EVs continues to grow, especially the race to achieve the longest range between automobile manufacturers accelerates the commercialisation of EVs. Further technological progress in batteries to optimize high power density, high energy density and to lower the costs will determine the penetration of the market and whether electric vehicles become industry standard (Dorcec et al. 2019; Bansal 2005).

From a technological standpoint, many MaaS platforms are already very advanced, allowing users to "plan, pay and access their mobility requirements whenever they want in a single application" (Arias-Molinares and García-Palomares 2020, 261). However, MaaS is still limited by technological aspects in the information and communications technology (ICT) infrastructure, which enables the standardization of data formats. This is needed to allow open data sharing via application programming interfaces (APIs) between MaaS providers and other transport operators (Arias-Molinares and García-Palomares 2020; Goulding and Kamargianni 2018). Additionally, a deciding factor in the coming years will be which platform can achieve scale by utilizing network effects to accumulate the largest user base (Tomaino et al. 2020).

2.3.2 Acceptance among customers and users

To achieve necessary acceptance around possible customers and users, it is of major importance for the AECM trends that they are sufficiently informed about the innovative technologies and their benefits, but also about their possible limitations. In addition, services must be designed and brought to market in a way that fits customers' and users' daily mobility patterns and mobility needs (Lagadic, Verloes, and Louvet 2019). Only if acceptance as well as resulting willingness to pay is ensured, the four key disruptive trends will become more established as industry standards within mobility. Differences between the trends can be observed with autonomous driving and connectivity facing some sort of scepsis, despite potential benefits, while electrification and MaaS are experiencing a growing acceptance.

The literature suggested that there is still some lack of interest or trust in AVs among the public (Schoettle and Sivak 2014; Thomas et al. 2020). Moreover, ethical, and moral dilemmas posed by autonomous driving, e.g., in the case of unavoidable accidents, exist not only because of legal considerations but also influence customer acceptance (Bonnefon, Shariff, and Rahwan 2016). Litman (2020) estimates that "it will probably be 2045 before half of new vehicles are autonomous" (5), which also can be explained with a slow customer and user acceptance, as it

is expected that the first higher-level autonomous vehicles will be “expensive, limited in performance, and will introduce new risks” (3). Thomas et al. (2020) emphasize the importance of user acceptance for the overall success of autonomous driving, as many of the concerns focus on possible system failures or malfunctions, or vehicle behaviour in unexpected situations. Concerns must be alleviated or eliminated if widespread use of autonomous driving is to be achieved.

Similar considerations apply to connectivity, as the industry may face some reluctance from customers and users to adopt the technology. Deloitte (2019) found in their study that customers would not be willing to pay more for services that enable vehicles to communicate with each other, even when thereby safety is improved significantly. Concerns are mainly related to data privacy and security against illegal access to the data. Therefore, transparent clarification about the handling and security of the data is recommended, to counteract the stronger perception of the disadvantages of CVs compared to the advantages and to increase the general acceptance (Schmidt et al. 2016; Ha et al. 2020).

Customer consideration for purchases of EVs has increased on average by around 21 percent from 2016 to 2019. However, conversion into purchases remains relatively low, indicating key concerns remain unresolved (McKinsey & Company 2019c). When it comes to electrification, the most important levers for increasing customer acceptance are vehicle range, the development of comprehensive and efficient charging infrastructure, costs of acquisition and affordable charging rates (Dorcec et al. 2019; McKinsey & Company 2019c). Nevertheless, the number of newly registered EVs is growing rapidly as mobility constitutes a key role in the sustainable consciousness of customers, creating a growing momentum for vehicle electrification and overall acceptance in society.

MaaS has also experienced great popularity in cities and has become an integral part of mobility in recent years. Machado et al. (2018) links this to “social and environmental concerns related

to vehicle ownership and urban living" (5). Moreover, users can easily improve their mobility journey by joining one single platform and experiencing great financial, sustainable, and convenience-related benefits leading to a growing acceptance and adoption of MaaS (Lyons, Hammond, and Mackay 2019; Butler, Yigitcanlar, and Paz 2020; Machado et al. 2018).

2.3.3 Legal and political requirements

Legal and political situations regarding the four key disruptive trends differ between countries and jurisdictions, which affects the commercial availability of the ACEM trends. Furthermore, as the impact of the ACEM trends is difficult to assess, it is challenging to implement appropriate policies and regulations.

As AVs are slowly starting to become more advanced, a societal and ethical conversation about legal implications needs to evolve into political regulations on a global scale. Legislators, liability insurers, and manufacturers must address legal and regulatory questions that are yet unanswered (Ilková and Ilka 2017). A recent example is the S-class model of Mercedes-Benz, which already enables level 3 autonomous driving, but only received regulatory approval for the technology in Germany in December 2021. The company now aims to receive regulatory approval in other jurisdictions as well (Bloomberg Green 2021). Increased autonomation and self-reliance lead to decisions, in some instances about life and death, being taken by algorithms instead of humans (Litman 2020; Beiker 2012). Furthermore, lack of clarity about liability in the case of accidents for passengers, manufacturers and other third parties along the supply chain leads to liability and reputational risks (Taeihagh and Lim 2019). Until these issues are not incorporated into a legal and policy framework, AVs will face challenges in becoming legally available to the public on a mass scale.

The adoption of connectivity in the mobility sector also requires legal and policy frameworks and regulations that consider public concerns and security issues related to data security and

privacy. Furthermore, legal and policy regulations and guidelines can support the establishment of unified communication between mobility users and infrastructure (Ha et al. 2020).

Few legal and political measures exist to incentivize and facilitate the diffusion of EVs, such as government subsidies for the acquisition or reductions of the ownership costs of EVs (Dorcec et al. 2019). In addition, regulations and bans on vehicles with internal combustion engines promote the spread of EVs for more environmentally friendly mobility (Arthur D. Little 2018). While most MaaS providers are private, public authorities play a key role in public transportation. Arias-Molinares and García-Palomares (2020) draw attention to challenges in the collaboration between private and public operators. There might be a mismatch between the objectives of private MaaS operators, respectively to operate efficiently and increase revenues, and public operators, to ensure sustainable, affordable, and accessible transportation to all members of society (Sochor, Strömberg, and Karlsson 2015; Arias-Molinares and García-Palomares 2020). Public transportation operators might not have the right incentive to join a shared mobility platform and existing market regulations limit the ability to capture the full value of mobility services (Accenture 2020).

2.4 Summary of literature review

During the last years, four key trends, *autonomous driving, connectivity, electrification,* and *mobility-as-a-service*, have emerged within the mobility sector. The literature review provided an overview of the academic and professional understanding of each key disruptive trend and pointed out the recent opportunities and challenges. *Technological advancements*, *acceptance among customers and users*, and *legal and political requirements* were presented as decisive drivers for the establishment of the trends within the mobility industry. In the following sections 3 and 4, two topics within the ACEM trends are addressed. Hereby, research gaps and opportunities for further research have been identified focusing on the EV battery recycling process in section 3 and in section 4 on the role of user experience in the mobility space.

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USER EXPERIENCES IN MOBILITY AND THEIR ROLE AS A COMPETITIVE DIFFERENTIATOR FOR THE MOBILITY OF THE FUTURE

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Abstract

This work “User experiences in mobility and their role as a competitive differentiator for the mobility of the future” contributes to clarifying the understanding of user experience in the context of mobility. Through six semi-structured interviews for data collection and analysis, the work identifies five key elements for the creation of user experiences in mobility: *value creation, characteristics, latest technologies, integrations and partnerships* and *viable business model*. Moreover, the findings of this work determine user experiences as a competitive differentiator for the establishment and success of key trends and their technologies in the mobility of the future.

Keywords: *Mobility, User experiences, Competitive differentiator, key disruptive trends, Mobility innovation*

4 Individual part II: User experiences in mobility and their role as a competitive differentiator for the mobility of the future

4.1 Introduction

Emerging innovations and technologies such as key mobility trends *autonomous driving, connectivity, electrification,* or *mobility as a service*, have the potential to change and transform the mobility industry, and therefore also the experience of drivers, passengers, and all other mobility users fundamentally (McKinsey & Company 2019a). They offer a variety of possibilities to change the way people perceive mobility in their daily life by potentially making mobility more flexible, accessible, sustainable, safer, and simply more enjoyable. Acceptance and wide public deployment of the technologies among the mobility key trends are also based on the expected value customers and users associate and experience with the new technologies, products, or services (Lyons, Hammond, and Mackay 2019; Thomas et al. 2020; Schmidt et al. 2016; Dorcec et al. 2019). Mobility demands and needs continue to evolve, presenting ever greater challenges for stakeholders and players to deliver the best experience (Frison et al. 2019). As a result, overall user experiences for mobility products and services deriving from the developments around key trends are getting more important to excite and convince customers (Körber et al. 2013). However, in academic literature, the role user experience plays in competitive success and the establishment of new technologies in the mobility industry is unexplored. Therefore, this work aims to contribute to filling this research gap and to encourage further research.

In the context of this work, the definition of the International Organization of Standardization (ISO) is consulted for a fundamental understanding of user experiences. Accordingly, user experiences are to be understood as “a person’s perceptions and responses resulting from the use and/or anticipated use of a product, system or service” (ISO 2010). However, a common understanding in academics and industry is still lacking (Law et al. 2008; Mirnig et al. 2015).

Based on qualitative research, in which six interviews were conducted with stakeholders from the fields of mobility and user experience design, this work contributes to clarifying the understanding of user experience in the context of mobility. Considering the developments and opportunities around mobility trends, this work aims to identify key elements for the creation of mobility user experiences. The resulting first research question examined in this work is:

RQ 1: *What are key elements for the creation of mobility user experiences?*

Furthermore, the goal of this work is to investigate the role of user experiences in the mobility space, especially as a competitive differentiator for the establishment and success of new technologies around key mobility trends. The resulting second research question is therefore:

RQ2: *Can user experiences be considered a competitive differentiator for emerging technologies in the mobility space?*

4.2 Research methodology and Analysis

Since user experiences are rather recent research phenomena in the mobility context, this work follows a qualitative research method, which is considered most suitable for gathering novel and comprehensive insights into a specific research topic (J. Corbin and Strauss 2014). In qualitative research, interviews are, especially in exploratory research such as this work, a widely used and efficient method of data collection characterized by knowledge and experiences shared by experts (Bogner, Littig, and Menz 2009). In total, six interviews were conducted between the 15th of October and the 26th of November 2021 with a duration ranging from 15 to 42 minutes. The first interview (I1) was conducted with an employee of a premium car manufacturer in the field of strategic development of digital services. Two further interviews were conducted with a venture designer and experience designer of a premium car manufacturer, who have established a division for user experience in the company (I4; I6). Another interview was conducted with a designer who works in the field of user-centred design for mobility companies such as car manufacturers or public transportation (I5). In addition, an

interview was conducted with a venture capital firm that operates an open innovation platform on mobility, scouting technologies from emerging start-ups for various car manufacturers and suppliers (I2). To also gain insights into possible new user experiences, an interview was conducted with a start-up creating a new in-car entertainment user experience (I3). The selected interviewees had proven experience of many years in the mobility space and field of user experiences and the different perspectives and backgrounds of the interviews were intended to provide holistic insights into the topic and the research questions. An overview of the interview partners can be found in the appendix (Appendix 6). By following a semi-structured guide with open-ended questions in the interviews, the conversations remained flexible to the interview partner's individual knowledge and insights while maintaining a thematic focus on the research question (see Appendix 7). The collected data was anonymized and transferred with the help of transcription software to better process the analysis (see Appendix 9). The detailed analysis of the collected interview data was following the inductive category formatting procedure according to Mayring (2014). This procedure starts with a deductive part, where categories are defined in advance based on theoretical considerations and the objectives of the analysis. Afterward, the collected material is worked through and assigned to the categories. If relevant material does not fit into a defined category, a new category is formulated. After all the material has been analysed, main categories are formed, under which the subcategories are assigned for a better overview of the analysis (Mayring 2014). Following this approach of inductive category formatting, 4 main categories with 13 subcategories in total were defined in this work. The tables of results for the respective categories in Appendix 8 are used as a basis for answering the research questions.

4.3 Key findings

In this part, the relevant findings from the analysis are presented to answer the two research questions. First, the topic of user experiences is classified in the context of mobility. Building

on this, identified key elements for the creation of mobility user experiences are described. Afterward, the role of user experience in the mobility industry as a competitive differentiator is analysed with the insights gained from the interviews. Furthermore, the interviews have provided insights into what future user experiences might look like and various start-ups were mentioned as examples of new mobility user experiences. Therefore, the in-car entertainment start-up holoride is presented as an example of a new user experience in the context of mobility.

4.3.1 User experiences in the mobility space

> *"Regarding user experience in mobility, we're still in the infancy of that discipline, (...)"*
>
> (Appendix 9, I4)

User experience in the mobility sector is a rather new topic that did not exist until a few years ago. For a long time, design in the automotive sector was mainly determined by exterior and interior design and the modelling of clay concepts. With the integration of more and more displays in vehicles, the design of user experiences has gained momentum and importance in recent years (Appendix 9, I4). Furthermore, with the progress in the developments of the key disruptive trends such as autonomous driving or mobility as a service, various opportunities open up for the creation of entire new user experiences (Appendix 9, I2). Mobility is a broad space and is involved in many aspects and situations of users' lives and the boundaries to other life experiences are blurring. At the same time, expectations and the perception of mobility have shifted. Users and customers are expecting more and new experiences and services while the actual driving experience moves into the background. Mobility is more than just getting from one place to another (Appendix 9, I2; I5; I6). However, not only in the mobility industry the topic of user experience is still often associated only with the interaction of screens or the design of an app (Appendix 9, I4; I5; I6). According to the experts' understanding, user experience is not about designing individual elements or making bigger screens in cars (Appendix 9, I4; I6). User experience describes the interaction with the mobility product or

service, but also with the overall ecosystem. And not only at a certain point in time. Rather, the interviewees emphasize user experience in mobility aims to cover the entire journey. The adjustment of the seat to the individual driver or the planning and coordination of the ride is part of the mobility user experience (Appendix 9, I6). Within mobility, user experience is looking at the pre-driving, the driving, and the post-driving experience and is not limited to digital touchpoints (Appendix 9, I4; I5; I6). In interview four it was noted that the mobility industry does not yet have a proper approach to user experience. According to the interviews, the topic of user experiences is still in its infancy in the mobility space with a lot of marginal problems to be solved first, before looking at a bigger vision (Appendix 9, I4; I6). Compared to other mobility experiences, for example, the car is a space that still can be enriched by many new experiences through different channels and technologies, compared to a first-class flight with available experiences regarding entertainment or service offerings (Appendix 9, I5).

4.3.2 Key elements for the creation of mobility user experiences

Through the interviews, five key elements for the creation of user experiences in mobility from a design and business perspective have been identified: *value creation, characteristics, latest technologies, integrations and partnerships* and *viable business model*.

First, the core element of mobility user experiences is *value creation*. It is important to create value for the user and customer. People differ in their mobility needs and requirements when they move, drive or travel. Moreover, differences between markets exist (Appendix 9, I1). To create mobility user experiences, a certain level of mobility functionalities is included, and the fundament is to serve the basic mobility needs, such as moving from one place to another (Appendix 9, I5; I6). For example, mobility and the driving experience can be seen as a source of entertainment or as an efficient mode of transport for commuters to get around (Appendix 9, I4). The interview partners, especially those with a background in design, emphasise understanding the different intentions, mobility needs and behaviours of users when creating

user experiences (Appendix 9, I4; I5; I6). Thereby, it is also about understanding the problems of potential users with the current mobility offers and finding solutions to create added value for them (Appendix 9, I5). Furthermore, a value-creating user experience can help overcome the uncertainty with new mobility trends such as autonomous driving and electrification (Appendix 9, I6).

The second key element is the *characteristics* of mobility user experiences. Building upon the first element, the ability to serve various mobility needs, user experiences in mobility have to allow customization to individual and specific needs (Appendix 9, I2). This step goes further than just serving the various basic mobility needs. Individual settings and wishes are recognized and customized from user to user. Intuitiveness is another important characteristic. When introducing new user experiences, it is important to guide the user along slowly and not overwhelm them. It is important to know the user's capabilities and previous behaviour when designing the user experience (Appendix 9, I5). New products and services and the corresponding user experience around them are designed for a certain purpose. However, the purpose is often reappropriated by the user during the initial period and the actual user experience falls apart (Appendix 9, I6). Therefore, it is an optimization process with continuous adjustments to create an intuitive user experience. Interview five highlights, from a user perspective, the most intuitive experiences are those that do not require any interaction: “the best interaction is no interaction at all” (Appendix 9, I5). Beyond that, important characteristics for mobility experiences are easy accessibility and ensuring the necessary availability and flexibility for the user (Appendix 9, I1; I2). From the perspective of an experience designer, user experiences also have to evoke emotions. These user experiences are the ones that will be remembered forever (Appendix 9, I6). In summary, characteristics considered for the creation of mobility user experiences are a high degree of customization, intuitiveness, accessibility, availability, flexibility, and emotional excitement.

The third key element is *latest technologies*, which are driving the creation of user experiences. Trends such as autonomous driving, connectivity, electrification, and mobility as a service reveal the opportunity to rethink the mobility experience and create entirely new user experiences (Appendix 9, I2). This implies that it is important to understand and be up to date with the latest technologies, which can enrich mobility user experiences. Moreover, technologies can help to anticipate users' needs and support the user experience with an even more intuitive solution (Appendix 9, I5).

Another element for the creation of user experience emphasizes successful *integrations and partnerships*. As already mentioned, the field of mobility is broad, and many different players and providers are involved, especially with increasing complexity, touchpoints, and interactions (Appendix 9, I2). The market of mobility providers is fragmented and at a certain point, several mobility experiences are often disconnected. With increasing multimodality in mobility, a cohesive experience is not yet possible (Appendix 9, I4; I5). Therefore, the integration of different services will be a key element for future user experiences in mobility. They are important if a holistic mobility experience that is convenient for the user is to be created. Partnerships can enable the integration of services or the interconnection of successive mobility experiences (Appendix 9, I2). Beyond that, partnerships can also bring entirely new experiences to mobility. An example is a newly founded partnership between the car manufacturer Mercedes-Benz and the sound-system Dolby Atmos, offering "state-of-the-art concert halls on the wheels" (Dolby Atmos 2021).

The last element for the creation of user experience is especially important from a business perspective: a *viable business model* defined around mobility user experiences. Insights from the interviews demonstrate, that new mobility user experiences were developed in the past, but the right business models were missing to capture the value (Appendix 9, I2; I3; I4). The interview partner from the fourth interview shared his experiences in the design studios of

various premium car manufacturers in California, where they developed working prototypes for new mobility products and exciting user experiences. What they had problems with, however, was that they did not find the right people within the mobility ecosystem with the entrepreneurial mindset and skills to build a working business model around it (Appendix 9, I4). It is not only important to assess the willingness to pay of potential customers and the problem-solution fit of new user experiences but also the overall business model is essential to bring them successfully to the market and sustain them in the long term (Appendix 9, I2; I3; I4). Therefore, Interview 2 recommended, people who are defining the business model around the experiences must be involved already early in the creation process to not only create unique but also profitable mobility user experiences (Appendix 9, I4).

4.3.3 User experiences as competitive differentiator

> *"It's an advantage for your product. If you're user experience is bad, your product is bad. It's that easy, a simple formula. Technologies are mostly all the same. (...) You make your decision to buy that technology based on the user experience."* (Appendix 9, I6)

User experiences in the car, but also in the entire mobility space are increasingly gaining importance among players ranging from arising start-ups to suppliers and established manufacturers, but also public transport operators. The interviewee responsible for technology scouting at various mobility players confirms that start-ups and solutions for user experiences are increasingly appearing on their radar (Appendix 9, I2). All the interviewees underlined that it is for players in the industry not only important anymore to offer great engines, the best performance, or attractive prices, but also additional services and a unique user experience (Appendix 9, I1; I2; I3; I4; I5; I6). To give a simplified example: With autonomous driving, one of the key trends, the actual driving itself is moving more into the background, and so new user experiences are determining the value of the mobility experience for customers. One of the

interviewees points out that competitors' technologies quickly converge over time and consequently they differentiate themselves through the user experiences created around the technologies, products, and services. Therefore, mobility players “will compete on user experiences” (Appendix 9, I6). Those that offer a holistic and unique mobility experience will retain customers and prevail in the long run. Once customers and users have discovered the added value, they will no longer return to old providers and outdated experiences (Appendix 9, I5). The interviews conducted and insights gained through the analysis make it clear that the creation of user experiences in the mobility sector are not only gaining in importance but will also represent a competitive differentiator in the future. The findings of this work show that those “who have solved the user experience best, win” (Appendix 9, I5).

4.3.4 Example of a new mobility user experience – holoride

The experts' insights showed that there is a lot of potential for the creation of new user experiences due to key trends around mobility such as autonomous driving, connectivity, electrification, and mobility as a service. One example is the German start-up holoride. Because a lot of time is spent on the road, the start-up holoride is aiming to make every ride a fun and connected experience and to turn transit time into valuable time. Holorides vision is to enable passengers to enjoy visual content in vehicles, by combining mobility with media. A unique in-car entertainment experience will be created, synchronizing Extended Reality (XR) content with the vehicle’s motion, position, and map data in real-time. Interactive content can be experienced much more realistically as the technology allows content to be adapted to vehicle movements, creating an even more intense and constantly changing experience. In addition, the motion-synchronized journey reduces the risk of motion sickness. Holorides solution not only opens entertainment opportunities but also enables other use cases to enrich the mobility experience for the user. For example, the technology can be used to enable interactive learning or to create a virtual desktop environment that enables productive work while travelling.

Moreover, a mindful and relaxing experience can be created that gives the user more than a simple ride. On their way to bringing such new user experiences into mobility, holoride has already realized first projects with car manufacturers such as Audi, Porsche, or Ford, but also with content suppliers such as Disney or Universal Studios (holoride 2021). The example of holoride is just one example of arising user experiences in the mobility space creating unique added value for users.

4.4 Discussion

The understanding of user experience in mobility that emerged from the interviews is largely in line with the fundamental definition provided by the ISO. Nevertheless, the experiences of the interview partners revealed that the topic of user experience is partially misunderstood in practice, not only in the mobility industry. A perception is anchored, that user experience is focused on digital touchpoints, mainly covering digital interfaces or apps. Thus, the term has often "been hijacked a bit by app and website designers" (Appendix 9, I5). However, the insights from the interview partners underline that user experience considers the entire experience of a product or service. Regarding the mobility space, the necessity to consider the holistic mobility experience is emphasized – the pre-driving, driving, and post-driving experience. In mobility, many user experiences follow another. From planning a trip, through the actual driving experience via multi-modal mobility solutions or the addition of entirely new user experiences, as the example of in-car entertainment has shown. In the future, it will be a challenge to seamlessly connect several experiences to create more and more of a holistic mobility experience for users despite different products, services, and providers they use during their journey. It will be important to accompany the customer along with the entire mobility experience, otherwise, you will lose the customer's interest along the journey. For example, if you do not manage to capture and support the user before the actual driving experience, you

will lose the customer and the intended driving experience will not happen at all (Appendix 9, I4).

The key elements identified for the creation of user experiences are not exhaustive and universally applicable, but as little is known about them in the academic literature, they contribute to understandings that are important for creating future mobility experiences. In this way, they can serve as guidelines or starting points. Especially in the mobility sector and around key trends such as autonomous driving, connectivity, electrification or mobility as a service, many things are new for users. Therefore, it is also important to operate in a forgiving way to slowly familiarize the user with new experiences and technologies, but also to continuously adapt to the user's behaviour. In this way, satisfying user experiences can help reduce uncertainty around new key trend technologies and accelerate market adoption in mobility. While most of the literature focuses on technology perspectives and advancements, this paper puts the user more in the foreground. Furthermore, the findings show that with rapidly converging technologies, the user experience will be a competitive differentiating factor in the future of mobility. The academic literature has already indicated that it is not only technologies that are crucial for the successful market establishment and competitive success (Zott, Amit, and Massa 2011; Chesbrough 2007). Chesbrough (2007) noted in today's fast-moving world innovative business models are a decisive factor and "a better business model often will beat a better idea or technology" (12). Findings and insights from the interviews regarding the need for viable business models as a key element for user experiences are in line with that view. With user experience being a competitive differentiator in the mobility of the future, another factor comes into play to successfully establish new technologies around key mobility trends in the market.

4.5 Conclusion

This work applied a qualitative research approach to contribute to the contextualization and understanding of user experience in the mobility sector. Insights were gained, that the topic of user experience has not yet fully arrived in the mobility sector and is still in the discovery phase. Based on the insights and experiences from the analysis of the interviews, this work suggests looking not only at the user experience as a single touchpoint at a certain point in time during the journey, but rather to think of the entire mobility journey – the pre-driving, the driving, and the post-driving experience. Building upon this, five key elements for the creation of mobility user experiences are identified, but also for possible completely new experiences: *value creation, characteristics, latest technologies, integrations and partnerships* and *viable business model*. In the mobility industry, with emerging key trends around the topics of autonomous driving, connectivity, electrification and mobility as a service, the findings of this work indicate that user experience can support the widespread deployment and adoption of those trends. The user experience represents a competitive differentiator for various mobility players in the future. Certain limitations must be acknowledged in the findings of this work. The sample size of this qualitative research was limited to six interviews. Moreover, with the interviews conducted with employees of a few players, only a limited number of perspectives on the topic of user experiences in the mobility context were collected. Therefore, the findings may not be representative of the entire mobility industry but provide a first understanding of user experiences in this industry. Furthermore, it should be noted that the assessments of the interview partners can be highly subjective and biased by their individual experiences. Future research is needed to explore the possible interplay of business models and user experience when it comes to converging technologies and their establishment and success in the market. In addition, this work encourages the exploration of user and customer expectations of the user experience in terms of key trends in future mobility.

5 General conclusion

This research provides insights into four key disruptive trends within the mobility space, which have the potential to change the mobility of the future: *autonomous driving, connectivity, electrification,* and *mobility as a service*. Within the literature review, the four key trends are introduced and requirements, which need to be met for the four trends to become industry standards are established. The requirements are divided and described in *technological advancements*, *acceptance among customers and users*, and *legal and political requirements*. The research made it clear that the key trends are at different stages of establishing themselves as industry standards and that there are still several challenges to overcome before the technologies are widely available.

The qualitative research sections deep dives into specific aspects of the identified literature. First, key challenges and possible solutions within the battery recycling process design of automotive manufacturers are identified and analysed. A framework is established, presenting the key challenges, which are based on *product-*, *resource-* and *economic constraints*. The framework additionally introduces possible solutions for the identified key challenges, which are split into *internal* and *external solutions*. This analysis provides automotive manufacturers with the possibility to optimize efficiencies in the battery recycling process design and thereby establish a competitive advantage.

This section is followed by a qualitative investigation of the role of user experience as a competitive differentiator for mobility in the future. An understanding of user experience in mobility is suggested, which covers the entire mobility journey and is not only focused on a single touchpoint with a product or service. With *value creation*, *characteristics* such as customization or intuitiveness, *latest technologies*, *integration and partnerships* and *viable business model* five key elements for the creation of mobility user experiences are introduced.

The key finding underlines, that the user experience represents a competitive differentiator for mobility experiences in the future and can facilitate the adoption of the key disruptive trends. From a practical standpoint, this work enables mobility players to identify a status quo of the four key trends within the mobility sector. It additionally provides a thorough identification of requirements to standardize and facilitate the implementation of the four key trends.

The authors acknowledge certain limitations such as the limited size of the study. By conducting larger studies with more companies and representatives from within and outside of the automotive sector, future research might gain even more in-depth insights and provide more detailed results. Including established, as well as new players from the mobility sector, the research could be enriched with various viewpoints. Additionally, when investigating the development and standardization of the four key trends, there is a degree of uncertainty due to the dynamics of technological advancements as well as political and consumer acceptance. Also, further research could focus on the four key trends not only from an individual perspective, but also study the effects and potential impacts on mobility when the trends are combined. Finally, other technological trends could be included in the research to broaden the perspective on future mobility.

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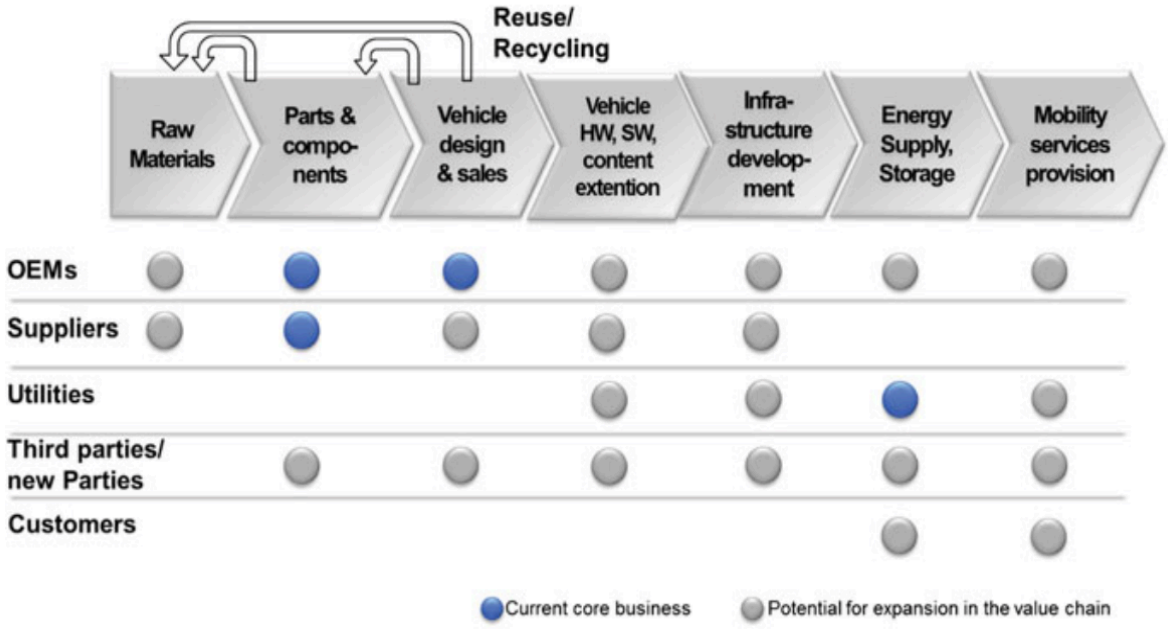
7 Appendix

Appendix 1: Transformation of mobility value chain



Source: Illustration from Fournier (2016), based on Fournier et al. (2012)

Appendix 2: Interviewed experts (Individual Topic I)

Company	Department	Role
Company A	Battery Analysis Centre	Manager
Company B	Battery recycling	Lead environmental engineer
Company C	Lithium-Ion Battery Recycling	Expert
Company D	Battery recycling	Strategy Analyst Battery Recycling
Company E	EV Battery Production	Lean Consultant and Planning Specialist

Appendix 3: Semi-structured interview guide (Individual Topic I)

1. **Introduction**
   - General information on work project and interview procedure
   - In which area are you working and what are your responsibilities?

2. **Battery Management**
   - Could you lead me through the current battery management process at your company?
   - From a process perspective what would you say are key factors that are relevant for successful battery management?
   - What role does sustainability play in battery management for your company?

3. **Battery Recycling**
   - What happens with batteries in EVs after their lifetime ends? Is the recycling process managed inhouse or outsourced? Why?

	- How does your company work together with external partners in battery management & battery recycling?
4. Industry Outlook	- How do you envision battery management will develop in the future? - What are key challenges and opportunities with battery management for automotive companies in the coming decades? - What would you estimate: When will there be sufficient battery management solutions in place to fulfil the demand of EVs as the standard solution?

Appendix 4: Inductive coding: Challenges (Individual Topic I)

Challenges	Sub-category	Factor
Product constraints	Transport of batteries	• Safety: Dangerous process due to inflammable and toxic material • Expensive process (safety material and logistics)
	Battery dismantling and disintegration	• Expertise: Complex process requires a lot of know how (esp. dismantling process)
	Product variance (5x)	• Low battery variance and similar set up necessary to create lean processes and reduce dismantling effort
Resource constraints	Human resources	• Expertise needed and many entire automotive industry looking for trained talent • Companies have different number of employees working in battery recycling (some more, some less)
	Inventorial resources	• Batteries take a lot of space and dangerous material cannot be stores for too long
Economic constraints	Costs	• High transport and recycling costs and no scalability enabling economies of scale
	Volume constraints	• Partners must be able to handle volume of automotive manufacturers

Appendix 5: Inductive coding: Opportunities (Individual Topic I)

Solutions	Sub-category	Factor
Internal solutions	Creation of centralized recycling location	• Reduces need for transportation • Reduces pressure on inventory management • Reduces costs

	Product Standardization	• Enabling economies of scale • Increases safety and efficiency of process
	Existing internal expertise	• Insights from hybrid battery recycling processes • Existing second life applications for batteries
External Solutions	Established network and expertise	• Utilize established processes and waste management network

Appendix 6: Overview conducted Interviews (Individual Topic II)

Overview Interview partners

Interview Number	Company and Role	Experience
Interview 1 (I1) *39 minutes, 15.10.2021*	Premium car manufacturer Strategic development digital services	- Development of digital charging service - End-to-end testing digital products - Selection of suppliers
Interview 2 (I2) *16 minutes, 05.11.2021*	Venture Capital & Open Innovation Platform for Mobility Ventures Associate	- Startup and technology scouting for mobility companies (e.g. OEMs and Suppliers) - Startup scouting for investment opportunities in wider mobility space
Interview 3 (I3) *23 minutes, 10.11.2021*	Mobility Startup focuses on In-car entertainment Business Development	- Inhouse Consulting experience - Creating new user experiences in the car, focusing on entire experience beyond driving
Interview 4 (I4) *42 minutes, 12.11.2021*	Premium car manufacturer Senior Venture Designer and former Director UI/UX Design and Prototyping	- Worked for premium automotive companies in the US Design studios on future of personal mobility and product innovation & UX Design for connected cars - Established first UI/UX design practice at German automotive company
Interview 5 (I5) *20 minutes, 15.11.2021*	Hello impact (Digital Product Innovation Agency) Designer and engineer in mobility space	- User-centered perspective for mobility experiences and beyond - Working with clients from mobility and cities (OEMs, Suppliers, Public transportation)
Interview 6 (I6) *31 minutes, 26.11.2021*	Premium car manufacturer Experience Design Director	- Experience Designer with working experience from Telecommunication and automotive - Was responsible for developing experience vision for E-mobility

Appendix 7: Semi-structured interview guide (Individual Topic II)

Interview guide

Topic	Questions
1. Introduction	- Please introduce yourself. In which area are you working and what are your responsibilities?

	- To what extent are you involved with new user experiences and the mobility space during your professional career? - What is your opinion on innovations and new business models in the context of future mobility?
2. User Experiences in mobility	- What role does the creation of new customer experiences play in the mobility sector? What does this mean for existing and future mobility players? - When did the topic of user experience become relevant in the mobility sector? - What were the drivers that made new user experiences more and more important? - How are new user experiences created? How does the design process look like? - What elements or factors constitute a unique user experience? - Can great user experiences be a competitive differentiator in the future of mobility? - How can new user experiences be integrated into existing mobility products or services? What problems are associated with this? - How can user experiences be transformed into viable, stand-alone business models? What problems are associated with this? - How can the experiences establish themselves as profitable business on the market? What (new) revenue streams are important?
3. Outlook User experiences in Mobility	- How do you envision mobility experiences and services in the future? - How can new user experiences within mobility look like? - What are arising startups or solutions in the field of user experiences in mobility?

Appendix 8: Results from analysis according to inductive category formatting (Individual Topic II)

Main category (I): User experiences in the mobility context

Subcategory *Category Label*	**Representative Quote** *(Interview source)*	**Outcome / Finding**
History *Historical developments of User experience in the mobility space*	- "As we know it now, so all I wanna say is when I started with this, there wasn't this thing called UX design and certainly not in automotive (…)" *(I4)* - "What really accelerated it was once there was more and more displays integrated into cars. Like the topic within cars really started to materialize and become like a serious thing. There is a clear point, which was when BMW introduced the iDrive." *(I4)* - "I would say the first time it was really taken serious is like, well after that, so it was maybe eight years ago. It's really more happening now for the past five years, maybe." *(I4)* - "Regarding user experience in mobility, we're still in the infancy of that discipline, (…)" *(I4)* - "I don't want to give you any vision about user experience because there's plenty of things that hasn't been solved yet." *(I6)*	- User experience in the mobility sector is a rather new topic that did not exist until a few years ago. The topic is still in its infancy and has gained momentum and importance especially in recent years with the integration of more and more displays in vehicles.

Shift in perception of mobility *How users and customers perceive mobility*	- "The car is probably not just about driving from A to B anymore, so there are requirements of customers and users that have shifted." *(I2)* - "(…) since there is a shift of the perception and how customers perceive the car they really want to have a new experience and this also includes the experience in and around the car." *(I2)*	- The customers perception of mobility have shifted. They expect more and new experiences and that mobility is more than just getting from one place to another.
Broad space of mobility *Mobility space characteristics*	- "And if you think about it, how many transactions does the car actually accompany? It takes me to the movies, it takes me to the supermarket, it takes me to kindergarten, which I also pay for. It's actually involved everywhere (…)" *(I3)* - "In first class on an airplane, the experience is already super mature, for example, also supported by flight personnel. In the car, the experience is still completely private and so it's a very rich area where you can still feed the experience through different channels. The different senses can be played with very richly using different technologies." *(I5)*	- Mobility is involved in many aspects of users' lives and the boundaries to other life experiences are blurring. - Compared to other mobility experiences, the car is an area that can still be enriched by many new experiences through various channels and technologies.
Understanding user experiences in Mobility context *Definition of User experience and particularities in mobility context*	- "(…) is that UX is really not limited to the digital touchpoints, right? (…) A UX designer doesn't really design the individual elements. He really looks at the entire user experience before and during and after the product is used." *(I4)* - "So therefore, my understanding is much broader and it goes beyond that screen. And I think that is ultimately what will be important to move that whole topic within mobility. Because per se mobility, isn't a fixed point in time. I think the complexity by designing UX for mobile products and businesses eventually is to look at the entire experience, which makes it rather challenging because at the end of the day for a business, you still need to focus on a certain aspect." *(I4)* - "And user experience is not only what happens on the screen, but it starts with which product I have to choose and what I have to do when I have bought the product. That's still the definition I attach to it, that it's not just the interaction with the product during use, but also what happens before and after." *(I5)* - "(…) it's not only about digital. Everybody associate user experience with something that is digital, but to me, sitting in a car arranging your seat is an experience, is a user experience. (..)To me, it's not only about interacting with the screen, but interacting with the overall product, but not only the product itself. You also need to look, how are you using this product. In our experience, when I was working with XY, mainly we always looked at the pre driving, then the driving and the post driving, which means actually a very classical customer journey. And you always need to look at the experience outside the car, but also inside the car. And how are these two interconnected?" (I6)	- User experience in mobility is not limited to digital touchpoints. It describes the interaction with the product or service, but also with the overall mobility ecosystem. User experience in mobility is looking at the pre driving, the driving, and the post driving experience and is aiming to cover the whole customer journey.

Main category (II): Key elements of unique mobility user experiences

Subcategory *Category Label*	**Representative Quotes** *(Interview source)*	**Outcome / Finding**

Various mobility needs and value creation *Various needs to be served and basic value creation (Job-to-be done)*	- "You also have to make the services market-specific, because a Chinese customer is quite differently than a European customer and an American customer." *(I1)* - "And I think the mobility services that will best adapt to the customer's needs and requirements will be most successful." (I2) - "And we know from cars and people that use cars, some people, they just look at it as kind of a piece of entertainment. They love to drive. (…) Everything you design, you need to design for that purpose. Others for them, it's mobility. That's basic mobility it is helping them from getting from one place to another more efficiently. And for them, other aspects are more important." *(I4)* - "There's maybe a person that's a daily commuter. Their main thing when it comes to mobility is to get to work, you know day to day. Then there's the people that their focus is more on Mobility as a journey." *(I4)* - "Additionally, there are some functionalities that they should serve. They should get a job to be done." *(I6)*	- People differ in their mobility needs and requirements when they move, drive or travel. - At the core of user experiences, it is important to create value for the user and customer. They have to serve the basic mobility needs and include certain level of functionalities.
Characteristics of unique user experiences *Characteristics of unique mobility user experiences*	- "And if you can use customized Services to configure the vehicle not just for one person, but for many, that's attractive." *(I1)* - "A product that is easy accessible, a product that creates value to the customer, which is very important. It needs to be exciting and new and maybe also allows them customization." *(I2)* - "This shows that sometimes you can't overtax users and have to introduce them to new solutions and experiences slowly and simply. That's why you always have to look at how you can get the user to use the new service or the new product. What are the capabilities of the user, it is also important to understand what are the motivation and possibilities of the user to create the change to digital." *(I5)* - "Because the best interaction is no interaction at all. (…) But I also believe that services and providers that offer an incredibly simple solution will win." *(I5)* - "These little things have to be intuitive. They have to be user friendly (…)." *(I6)* - "How can I make mobility even simpler, more flexible and more intuitive than it is today." *(I1)* - "Then you have the experience that could be about surprise and emotional. (…) This is something you don't really need, but it brings a nice emotion to the customer. (…) But then you have emotional experiences. (…) You don't need this but that's something emotional. That's something you'll always remember. (…) Focus on how can I make my experience memorable that people would come back again and say that was amazing." *(I6)*	- Unique user experiences make it possible to adapt vehicles and mobility services to different needs. They allow customization to specific and individual needs. - When introducing new user experiences, it is important to guide the user along slowly and not overwhelm them. It is important to take into account the user's capabilities and previous behaviour when designing the user experience. - Unique user experiences are the ones that evoke emotions. They are easy accessible, flexible and characterized by an intuitive experience.
Technologies *Role of technology and ACEM trends for user experiences*	- "(…) we need to understand the possible future technologies that can play a role in mobility. You have to understand what is state-of-the-art in the technologies to then develop user experiences that are supported by the technologies." *(I5)* - "That all the technology and AI doesn't irritate you so much but supports you and anticipates things like that." *(I5)*	- Opportunities for new and more advanced user experiences are driven by ACEM trends and the latest technologies. - It is important to understand and be up to date with the latest

	- "I definitely see that new user experiences or user experiences in general play an important role and definitely are getting more important. And this is probably also driven by trends like autonomous driving, by shared mobility services and also E-mobility." *(I2)*	technologies in order to anticipate users' needs and help them fulfil them to create a unique user experience.
Integration and partnerships *Interplay of different players*	- "And to make another example, the market is kind of fragmented when it comes to car sharing, there are a lot of different apps, different services, and maybe also aggregating those services would be sort of an idea to move forward in that direction." *(I2)* - "It makes it much easier if we partner with existing suppliers of car manufacturers to be compatible even faster. It's about middleware players, about audio players, it's also about technology players in the direction of autonomous driving, where we can design things. The more deeply we can create and link our own added value, the greater the added value is for the customer." *(I3)* - "The biggest challenge with mobility is, you have so many touchpoints, so how do you get these? And unless you can't afford to own all those touch points, there will always gonna be a break in the experience." *(I4)* - "But it's also about integration, because I don't always want to switch between different apps and different services. That you can travel multi-modally easily and comfortably." *(I5)* - "You probably have to create partnerships in the future. I think collaboration is an important factor." *(I2)*	- Mobility is a broad field in which many different players and providers are active, with increasing complexity and many touchpoints and interactions. - The market of providers is fragmented and with increasing multimodality in mobility, a cohesive experience is not yet possible. Therefore, the integration of different services and partnerships is important if a holistic mobility experience that is convenient for the user is to be created. - Partnerships also make it possible to bring entirely new experiences to mobility.
Business model *Relevance of business model around the user experience*	- "And as mentioned before, maybe some kind of a business model that has the ability to include other services, aggregates other services." *(I2)* - "You also have to ensure that customers are willing to pay for services." *(I2)* - "We know it would be great product, but we don't know if people will pay for this." *(I4)* - "We've created smart and electric mobility products when we had models and prototypes that are actually working out there. But we always struggled to find the people in the mobility ecosystem that would help us build a business case around it. We always knew we needed that. (…) If you have someone that is creative from a business perspective, you want to be interacting with that person or that with that group already early on in the design process. (…) interacting with entrepreneurs or people that know how to define the business part around this offering." *(I4)*	- Introducing new user experiences, providers have to ensure that it is worth it for customers to pay extra for it. - New user experiences and mobility services were developed, but the right business model was missing. - It is crucial to build a working business case around new mobility user experiences. People who are defining the business part around the experiences have to be involved already early on in the design process.

Main category (III): User experiences as competitive differentiator

Subcategory *Category Label*	**Representative Quotes** *(Interview source)*	**Outcome / Finding**
Importance *Classification of the relevance of user experiences in mobility*	- "And a big field is definitely new user experiences related to the car, but also to the whole mobility space. And that means I was working on a lot of tech requests in that space and sourcing technologies, which fit into that area." *(I2)*	- New user experiences in the car, and entire mobility sector, are increasingly gaining importance among players in the mobility sector, from arising start-ups to suppliers

	- "I think that because the pressure and the time to deal with it is getting bigger and bigger, the topic user experience is becoming more and more relevant." *(I3)* - "I believe that experience design is much, much more important than horsepower." *(I6)*	and established car manufacturers, but also public transport operators.
Competitive differentiator *Potential of user experiences as competitive differentiation*	- "And what else is important for brands and for mobility providers to not only differentiate as a car brand or as a mobility provider by offering a nice design or great engines or attractive prices but also by offering additional services and creating a new experience for the customer." *(I2)* - "As soon as customers experience a more and more holistic mobility experience with additional services, they won't want to leave. And the manufacturers win." *(I5)* - "It is an advantage for your product. If you're user experience is bad, your product is bad. It's that easy. It's a simple formula. Technologies are mostly all the same. (…) You make your decision to buy that technology based on the user experience. Not only about how it looks but how it works too. I believe user experience is definitely a mandatory requirement. For every product and service. Now and in the future." *(I6)* - "Manufacturer or providers compete on user experiences. They don't compete on quality anymore. Quality of course is very important but. Now they focus on how can I make my experience memorable that people would come back again and say that was amazing. I wanna tell everybody about." *(I6)*	- Technologies will converge between providers over time. Mobility providers will therefore differentiate themselves through additional services and new user experiences created. Competition will be on the user experiences they offer to customers. - Those that offer a unified and unique mobility experience will win over customers and prevail in the long run. Once customers have discovered the added value, they will no longer return to old providers and outdated services.

Main category (IV): Outlook into the future of user experiences

Subcategory *Category Label*	**Representative Quotes** *(Interview source)*	**Outcome / Finding**
Potential for start-ups *New players entering the field (Start-ups…)*	- "Customers expect new experiences and want new experiences. This means there is a lot of potential in the space and also for start-ups." *(I2)*	- In the mobility space for creating new user experiences there is a lot of potential for arising start-ups
Examples *Use cases for new user experiences*	- "Let's say wellness or wellbeing in the car. I think health related topics in the car are getting more and more attention. Well-being for drivers, but also passengers. And safety of passengers and the drivers are definitely topics which are, I think, of high importance for mobility providers. But also services that insure when it comes to shared mobility that the cars are clean." *(I2)* - "What I also find very interesting is the gaming example of Holoride, who did it together with Audi. I think that's a solution that again is much more targeted at the user, also at the cost contribution or also at the OEM." *(I3)*	

Appendix 9: Interview transcripts – Individual Topic I & Individual Topic II Individual Topic I:

See additional upload - (Part 2) 2021-22_Fall_ 46182_Tim Becker_Part 2_Appendix 9