The Future of Mobility

Impact of robotaxis on the European passenger transportation industry

Luca Mische
152118352

Dissertation written under the supervision of André de Almeida Pinho

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Abstract

Title: The Future of Mobility - Impact of robotaxis on the European passenger transportation industry

Author: Luca Mische

Automation, connectivity, electrification, and shared mobility are the dominant trends transforming the passenger transportation industry. Together they form what is considered one of the most disruptive means of transportation of the future, the robotaxi. This master thesis explores the impact of robotaxis on the future of the passenger transportation industry, with particular attention to the usage perspectives and mobility behavior of consumers. The results are based on an exploratory analysis involving seven in-depth semi-structured expert interviews, a consumer survey, and existing literature. Usage perspectives were observed through a use case analysis that identified work-related commuting as the use case with the highest application potential. In the light of work-related commuting, the thesis revealed that robotaxis significantly reduce commuters' value of time and display an attractive mobility alternative from a cost perspective. In addition, it is shown that in the next ten years, consumer preferences regarding consumers' transportation choice significantly shift towards robotaxis. The research reveals that the industry's most likely future state is characterized by the gradual introduction of robotaxis. Therefore, in five to ten years, robotaxis are used by early adopters and will impose significant changes in industry dynamics as competition increases and new revenue streams emerge. The results intend to enable industry players to target specific consumers, derive strategic implications, business models, and vehicle concepts. Further, they contribute to an objective scientific, political, and social discussion and serve as a basis for further research in the field of robotaxis.

Keywords: Robotaxi | Passenger transportation industry | Future of mobility | Consumer perspective | Mobility behavior | Autonomous driving

Sumário executivo

Título: O Futuro da Mobilidade – O Impacto dos Robotáxis na Indústria Europeia de Transporte de Passageiros

Autor: Luca Mische

Automação, conectividade, eletrificação, e mobilidade partilhada são as tendências dominantes que têm transformado a indústria de transporte de passageiros. Juntos, formam um dos meios de transporte mais disruptivos, o robotáxi. Esta tese explora o impacto dos robotáxis no futuro desta indústria, focando-se nas perspetivas de utilização e no comportamento de mobilidade dos consumidores. Os resultados baseiam-se numa análise que inclui sete entrevistas feitas a peritos, um inquérito aos consumidores e na literatura existente. As perspetivas de utilização foram observadas através de uma análise de caso de uso que identificou as deslocações para o trabalho como o caso com maior potencial de aplicação. Revela-se que os robotáxis reduzem significativamente a perceção de tempo gasto nestas deslocações e constituem uma alternativa de mobilidade atrativa do ponto de vista monetário. Adicionalmente, mostra-se que, nos próximos dez anos, as preferências dos consumidores em relação à escolha de transporte mudarão significativamente havendo uma tendência para a adoção de robotáxis. Este estudo revela que o futuro da indústria será marcado pela introdução gradual de robotáxis. Assim, dentro de cinco a dez anos, os robotáxis serão utilizados pelos consumidores pioneiros na adoção e irão impor mudanças significativas na dinâmica da indústria à medida que a concorrência aumente e surjam novos fluxos de receitas. Os resultados do estudo pretendem permitir aos agentes desta indústria focar-se em consumidores específicos, retirar implicações estratégicas, modelos empresariais, e conceitos relacionados com veículos. Adicionalmente, contribuem para uma discussão científica, política e social e servem de base para mais investigação no campo dos robotáxis.

Palavras-chave: Robotáxi | Indústria do transporte de passageiros | Futuro da mobilidade | Perspectiva do consumidor | Comportamento de mobilidade | Condução autónoma

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List of Abbreviations

ADAS	– Advanced Driver Assistance System
AI	– Artificial Intelligence
AV	– Autonomous Vehicle
Avg.	– Average
CAV	– Connected autonomous vehicle
e.g.	– Exempli gratia / for example
Et al.	– et alia/ and others
etc.	– Et cetera
EV	– Electric vehicle
EU	– European Union
GHG	– Greenhouse gas
GM	– General Motors
GPS	– Global positioning system
GDP	– Gross Domestic Product
ICT	– Information and Communication Technology
IoT	– Internet of Things
Lidar	– Light detection and ranging
MaaS	– Mobility-as-a-Service
Min	– Minute
MoD	– Mobility on Demand
OEM	– Original Equipment Manufacturer
PPP	– Purchasing power parity
R&D	– Research and development
SAE	– Society of Automotive Engineers
V2C	– Vehicle to cloud
V2I	– Vehicle to infrastructure
V2X	– Vehicle-to-everything
V2V	– Vehicle-to-vehicle
WA	– Weighted Average

1. Introduction

Over the last two centuries, the evolution from steam to fuel-powered transportation was one of the primary enablers of the industrialization and global economic growth (Bösch, 2018). Fueled by the digitalization and urbanization, urban mobility is again undergoing a profound and fundamental change with car manufacturers facing the major task of rethinking their products and services (Stricker et al., 2018). Today, automation, connectivity, electrification, and service-oriented mobility solutions are regarded as the dominant industry trends to shape the future of passenger transportation (Ambadipudi et al., 2017; Modi et al., 2018). The combination of these trends form what is described as one of the most fascinating, but also one of the most indistinct visions of the future automobile: the robotaxi (Stegmüller et al., 2019).

Robotaxis, as self-driving, electric vehicles that provide point-to-point transportation, will change the industry's paradigms with positively contributing to the current transportation system (Stegmüller et al., 2019). Positive effects on traffic flow, road safety, pollution, and travel costs for the consumers are expected. Furthermore, they serve as an accessibility enhancer for those who cannot drive themselves or do not own vehicles (Bagloee et al., 2016). With these and other advantages, robotaxis can take over a significant proportion of the traffic currently handled by conventionally powered cars and public transportation (Becker & Axhausen, 2019; Bischoff & Maciejewski, 2016). The high potential of robotaxis as a new mobility concept encouraged several companies to enter the self-driving vehicle market (Bischoff & Maciejewski, 2016). Although some firms began running pilot projects early on (Wintersberger et al., 2019), it is unclear at what point in time robotaxis will become available.

The introduction of robotaxis is highly dependent on the mobility behavior of consumers and their acceptance towards the new mobility concept (Zmud & Sener, 2017). The mobility consumption pattern of consumers has changed in recent years. Ownership became less important, while the temporary access to goods and services became more popular (Bardhi & Eckhardt, 2012). At the same time, cars lose their function as a status symbol, which encourages a shift towards shared services (Herrmann et al., 2018). Robotaxis could also contribute to a significant change in consumer behavior with regard to the choice of transportation. However, from a consumer perspective, robotaxis only appeared as a hypothetical mobility concept. Therefore, it remains to be seen whether the consumer acceptance is sufficient for the robotaxis success (Stegmüller et al., 2019).

Previous research is primarily concerned with the technical implementation or digital possibilities of integrating self-driving vehicles into the existing vehicle market. As the success of a mobility concept is determined rather by the potential to satisfy customer needs than by its technical superiority (Henkel et al., 2015), the underlying research aims to examine the application possibilities and the influence of robotaxis on consumer preferences regarding consumers' transportation choice. Furthermore, it aims to provide an outlook on the industries future path. To do so, the following research questions are investigated:

Research question 1:
What is the impact of robotaxis on the European passenger transportation industry?

Research question 2:
How will the future path of the European passenger transportation industry look like five to ten years from now?

By answering the research questions, the effects of the COVID-19 outbreak were excluded since long-term consequences for the passenger transportation industry cannot be foreseen at this point in time.

The research findings enable industry players to target specific consumers and derive strategic implications, business models, and vehicle concepts. Additionally, this research aims to contribute to an objective scientific, political, and social discussion on robotaxis.

The thesis at hand, is structured as follows. First, an overview of existing literature on the passenger transportation industry, the concept of robotaxis, and robotaxis current state of development is provided. Afterward, the research methodology, including the research design and the data collection process, is elaborated. The following fourth chapter is split into two parts. The first part answers RQ1 and determines the application potential of robotaxis for several use cases. Based on the use case with the highest application potential, the impact of robotaxis on consumers mobility behavior is examined. The focus lies in identifying changes in the value of time, the monetary costs, and consumer preferences. The second part of chapter four focusses on answering RQ2. To provide a comprehensive analysis of the industry's future state, an outlook on three possible future scenarios is provided, including a detailed explanation of the most probable scenario. The following results are used to derive strategic implications for stakeholders within the passenger transportation industry. Lastly, the thesis concludes the findings in the light of research limitations.

2. Literature review

This chapter provides an overview of existing research in the field of passenger transportation and robotaxis. The literature review is subdivided into three sections and covers the status quo of the passenger transportation industry, including its trends and challenges, the concept of robotaxis, and robotaxis current state of development

2.1 Passenger transportation industry

2.1.1 Road transportation and the automotive sector

European road passenger transportation is dominated by the passenger car (Destatis, 2020a). The private automobile is considered the most popular transportation mode, accounting for 83% of road passenger transportation (Destatis, 2020a). The automotive sector is considered as one of the largest industrial sectors worldwide with an essential share of gross domestic product (GDP) and employment in the G7 countries (Jacobides et al., 2016). With approximately 15.3 million new car registrations in 2019, Europe-28 is among the three largest automobile markets worldwide (VDA, 2020). In 2018, 268 million passenger cars were in use in Europe (Eurostat, 2019), and the annual turnover represented over 7% of the EU GDP, which amounted to $18.8 trillion (Stolfa et al., 2020; The World Bank, 2020). In 2017, accounting for 28% of total EU spending on Research and development (R&D), the automotive sector was Europe's most significant private contributor to innovation, investing €57.4 billion (ACEA, 2019).

2.1.2 Mobility options of road transportation

Adequate mobility opportunities and excellent transport provision are fundamental in ensuring that the city is accessible to all citizens (Gebhardt et al., 2016). Mobility options can be differentiated between accessibility (private vs. public), use (shared vs. individual), and the distance between starting point and destination (local vs. long-distance transport) (Ammoser & Hoppe, 2006).

<u>Private transport</u>

Private transport describes the personal and individual use of commercial and privately-owned vehicles (Ammoser & Hoppe, 2006). It includes private cars, motorcycles, bicycles, and others (Ammoser & Hoppe, 2006). Among these, the private car is deemed as the most convenient and flexible ways to travel (Gebhardt et al., 2016). Nevertheless, not everyone can afford the high costs of ownership. Therefore, many people living in urban areas also use public transport or other mobility alternatives (Gebhardt et al., 2016).

Public transport

Public transport represents a system of vehicles such as buses and trains that carry a large number of passengers on predetermined routes and schedules (Santi & Ratti, 2017). Although public transportation is a socially acceptable mobility alternative from the cost perspective, people cannot access all places in a city. Therefore, on many routes, the last mile has to be covered by alternative modes of transportation (Gebhardt et al., 2016).

Mobility on demand (MoD)

One alternative to the previously mentioned transportation options are mobility on demand (MoD) offerings such as shared mobility services. Shared mobility describes the joint use of a car, bicycle, or any other means of transportation that gives passengers temporary access to mobility options on an on-demand basis (Novikova, 2017; Shaheen & Chan, 2016). Taxis, car or ride sharing programs (e.g., ShareNow and BlaBlaCar), and ride-hailing programs (e.g., Uber and Lyft), are only a few examples of shared mobility concepts. The advantage of shared mobility is that it maximizes vehicle utilization through sequential access by multiple users (Le Vine & Polak, 2015) and serves as an accessibility enhancer for those who are unable to drive or do not own vehicles (Lavieri & Bhat, 2019).

2.1.3 Mobility challenges

Although mobility promotes the prosperity of societies and functionality of cities for a better quality of life, some challenges inevitably remain (Bagloee et al., 2016). Urbanization, environmental pollution, and road safety are only some of the challenges that are influencing the transportation industry (European Commission, 2019b).

Urbanization

Today, 55% of the world population currently lives in urban areas, and it is expected that the proportion will increase to 68% by 2050 (UN DESA, 2018). In addition to the gradual relocation of inhabitants from the countryside to the city, the world's population is growing and could bring another 2.5 billion inhabitants to the metropolises by 2050 (UN DESA, 2018). As the population in cities continues to grow, the need for mobility rapidly increases (Seuwou et al., 2020). The perhaps the most visible problem of urbanization for passenger transport is disruptive traffic flow (Corwin et al., 2019). In 2015, European commuters spent on average between 45 (Paris) and 101 (London) hours in traffic jams (INRIX, 2015), contributing not only to disruptive traffic flow but to a considerable amount of the world's greenhouse gas (GHG) emissions (Santi & Ratti, 2017).

Environmental pollution

As today's transportation sector is mainly based on the combustion of fuel, it is a major contributor to the production of CO_2. With over 20% of global CO_2 emissions from the combustion of fossil fuels, the transport sector (road, rail, air, sea) is one of the main sources of global GHG emissions (Bubeck et al., 2016). In 2016, road transportation alone was responsible for nearly 27% of Europe's total CO_2 emissions (BDL, 2019). Climate policies and advancing technologies in alternative drive systems are leading to an industry-wide change in the way cars are powered and forcing car manufacturers to adapt to this challenge (Bubeck et al., 2016).

Safety

Around 1.35 million people die each year from traffic accidents (WHO, 2018). In 2017, approximately 25,000 road deaths and 1.08 million traffic-related injuries occurred on the roads of the EU-28 (European Commission, 2019a). According to the National Highway Traffic Safety Administration (NHTSA) (2018), approximately 94% of traffic accidents can be attributed to human error. Road safety has also been acknowledged as a major challenge by the United Nations General Assembly, which introduced an action plan to stabilize road traffic and reduce traffic accidents (UNDSS, 2019).

2.1.4 Trends shaping mobility

Technological innovations, such as autonomous driving, vehicle connectivity, and powertrain electrification, coupled with shared mobility, are the key drivers of the digital transformation in the passenger transportation industry (Stegmüller et al., 2019). These new trends can jointly create an intelligent transportation system that can meet the aforementioned industry challenges by reducing traffic accidents, congestion, and environmental pollution while improving transport accessibility (Bagloee et al., 2016; European Commission, 2019b; Faisal et al., 2019; Möller et al., 2019). These trends are expected to change the automotive paradigms and encourage car manufacturers to collaborate with other mobility providers, start-ups, or software companies (Bailo et al., 2018; Herrmann et al., 2018).

Autonomous driving

An autonomous vehicle (AV), often also referred to as a self-driving car (Litman, 2020a), driver-less car (Hörl et al., 2016), robocar (Herrmann et al., 2018), or robotic car (Fernandes et al., 2014) is a vehicle that has self-contained decision-making capabilities, is capable of sensing its environment and moving safely with little or no human intervention (Shladover, 2017). To distinguish between different grades of autonomy, the Society of Automotive Engineers (SAE

International, 2018) introduced a six-levels taxonomy, ranging from level 0, no driving automation, to level 5, full automation. Vehicles of SAE levels 0 to 2 are considered "traditional", as the environment is still monitored by the driver (Martínez-Díaz & Soriguera, 2018). From levels 3 to 5, the vehicle collects and interprets all necessary data from the environment itself (Martínez-Díaz & Soriguera, 2018). While a growing number of vehicles are equipped with SAE levels 1 or 2, vehicles of levels 3 to 5 are not yet available to the general public, apart from a few pilot projects (Bailo et al., 2018). The complete six-step taxonomy can be found in Appendix A.

Vehicle connectivity

For road transportation to function as a well-integrated intelligent system, the connectivity of infrastructure, cars, and other road users, is required (Bagloee et al., 2016). The prerequisite for a connected autonomous vehicle (CAV) is wireless connectivity between the car and its environment, known as vehicle-to-everything (V2X) communication. V2X consists of various components, such as vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) or vehicle-to-cloud (V2C) communication (Shladover, 2017). In addition, cars must be responsive to all other personal devices and road users, such as pedestrians or cyclists, in order to ensure road safety (Bagloee et al., 2016). Communication between all road users occurs via a real-time exchange of data and is controlled by devices in an Internet of Things (IoT) environment. IoT describes the interoperable exchange of information between any physical object, system, or cloud infrastructure via the internet (Zanella et al., 2014). For seamless communication with the environment, the CAV accumulates and records all data around the vehicle using a global positioning system (GPS) and a sensing system, which includes a variety of sensors (e.g., LIDAR (light detection and ranging)), cameras, and radar. Based on this data, appropriate courses of actions are recommended by the vehicles software which allows the car to navigate safely through its environment (Bagloee et al., 2016; Shladover, 2017; Zanella et al., 2014).

Electrification

Since the transport sector is one of the primary sources of global greenhouse gas (GHG) emissions, alternative driving systems can significantly contribute to climate protection (Bubeck et al., 2016). Increasing regulation of CO_2 and pollutant emissions, as well as the ambition to reduce the dependence on fossil fuels, are the main drivers for the electrification of vehicles (ERTRAC, 2017). Although electric vehicles (EV) sales have proliferated over the last decade, the global share of electric vehicles is less than 1% of today's total vehicles in use worldwide (Teter et al., 2019). Substantial investments in battery technology by car manufacturers and a more widespread charging infrastructure have led to an increasing worldwide acceptance of EVs during the last years. (ERTRAC, 2017). While about 5.6 million EVs were registered worldwide in 2019, the number rose to 7.9 million in 2020 (ZSW, 2020). With nearly 361.000 EVs sold in 2019, Tesla is the leading car manufacturer in the EV market (ZSW, 2020). With a possible reduction in the cost of battery technology and a comprehensive charging infrastructure, electric cars may represent a significant share of the entire vehicle fleet in the future (Mosquet et al., 2018).

Shared mobility

Redefined by technology and peer communities, the field of shared mobility has experienced a growing interest among researchers in recent years (Novikova, 2017). Especially consumer research bears considerable attention to a consortium of affiliated business and consumption practices (Belk, 2014), which can be described as "sharing" (Belk, 2010), "access-based consumption" (Bardhi & Eckhardt, 2012), or "collaborative consumption" (Botsman & Rogers, 2010). The attention results from the emergence of various businesses that are prospering due to the proliferation of the "sharing economy" (Belk, 2014). The sharing economy is characterized by consumption models in which access is provided through the sharing or pooling of resources, products, or services (Bardhi & Eckhardt, 2012; Botsman & Rogers, 2010; Santi & Ratti, 2017). Examples of such consumption models are, as previously mentioned, shared mobility programs (e.g., ShareNow or Uber) or accommodation marketplaces (e.g., Airbnb) (Bardhi & Eckhardt, 2012). Propelled by the widespread usage of Information and Communication Technology (ICT) and the continuously increasing urban density, several new services have emerged in the shared mobility market (Kamargianni & Matyas, 2017; Le Vine & Polak, 2015), shifting consumer preferences away from ownership-based towards access-based mobility (Belk, 2014). Cost consciousness, user convenience, accessibility of location, environmental awareness, and other factors contribute to the rapid increase in popularity of sharing services (Novikova, 2017; S. A. Shaheen et al., 2012).

2.2 The concept of robotaxis and the relevance of autonomous driving

The four industry trends – autonomous driving, connectivity, electrification, and shared mobility – are prerequisites for the autonomous vehicle on-demand concept (Ambadipudi et al., 2017), often referred to as robocab (Stegmüller et al., 2019) or robotaxi (Cervero, 2017). Robotaxis are self-driving electric vehicles that enable passengers' point-to-point transit on an on-demand basis (Beiker, 2016; Pavone, 2015; Stegmüller et al., 2019). In analogy to today's ride-hailing services, consumers would summon robotaxis via a smartphone application whereby payment is based on different vehicle types, trip duration, and travel distance (Pavone, 2015; Stegmüller et al., 2019).

Robotaxis are expected to operate as SAE level 5 AVs and are supposed to bring significant benefits for passenger transportation (Becker & Axhausen, 2019). In particular, they are expected to increase road safety (Fagnant & Kockelman, 2015) and reduce costs of travel (Bösch, 2018), pollution, congestion, and the demand for parking spaces (Gill, 2020; Lang et al., 2016). Apart from that, the exclusion of the driving tasks allows passengers to focus their attention on other activities during the trip (Trommer et al., 2016). Furthermore, it is expected that robotaxis maximize the vehicle utilization through sequential access by multiple users (Bagloee et al., 2016). By maximizing the vehicle utilization, robotaxis can significantly reduce the number of conventional cars on the road and still meet the mobility needs of society (International Transport Forum, 2015).

The challenge in the introduction of level 5 AVs is to develop a reliable and safe system that is powerful enough to transmit the enormous amount of high-speed data so that the vehicle can communicate with its environment and thus ensure road safety (Kaur & Rampersad, 2018). However, technology still has performance shortcomings, and the reliability with which the car can handle unforeseen traffic situations is not yet given (Martínez-Díaz & Soriguera, 2018). Besides technological requirements, other factors that pose a challenge for the implementation of Level 5 AVs are legal frameworks, regulatory requirements, ethical concerns, or cybersecurity (Herrmann et al., 2018).

As a result of these challenges, car manufacturers do not expect to commercially launch fully self-driving cars in the short-term (Martínez-Díaz & Soriguera, 2018). Existing literature serves a fragmented picture of autonomous vehicle implementation. Optimistic scholars anticipate that within the next five years, between 2020 and 2025, self-driving vehicles equipped with the highest level of automation will be implemented (Arbib & Seba, 2017; Herrmann et al., 2018; Zmud et al., 2017). On the other hand, conservative scholars assume that level 5 AVs will be commercially available by the end of the 2020s or even later and will account for a significant proportion of vehicles in use only when they become affordable for the mass market, which will be in between 2050 and 2060 (Bansal & Kockelman, 2016; Lavasani et al., 2016; Litman, 2020).

2.3 Robotaxis' current state of development

While a growing number of vehicles are equipped with SAE levels 1 or 2, vehicles of levels 3 to 5 are not yet available to the general public, apart from a few pilot projects (Bailo et al., 2018). Pioneers such as Waymo or Uber began running pilot projects early on for level 3 and 4 vehicles and provided groundbreaking technologies for various OEMs to design their AV programs and prototypes (Wintersberger et al., 2019). It is expected that the ongoing developments of self-driving vehicles will sooner or later result in commercial robotaxi services (Bischoff & Maciejewski, 2016).

In 2016, the world's first public trial of a robotaxi service was introduced in Singapore's university district by the United States (US) based company nuTonomy (Herrmann et al., 2018; Vasagar, 2016). While operating its robotaxi service, nuTonomy partnered with Lyft and PSA Group and was acquired in 2017 for around $450 million by Delphi automotive (Abuelsamid, 2017). The Google subsidiary Waymo, also operates its own automated ride-hailing service, namely Waymo One, in a small restricted area in the United States, where they conducted millions of kilometers of on-road testing (Ohnsman, 2018; *Waymo LLC*, 2019). Several other companies, including Uber, Tesla, Apple, Cruise Automation, Aurora, and others, are also focusing on their own automated ride-hailing services by developing AV technologies either alone or in collaboration with automakers (Uber, 2019). Uber, for example, collaborates with Toyota and has been involved in on-road testing for some time. Although Uber experienced a significant setback in March 2018, when in Tempe, Arizona, a test vehicle struck and killed a pedestrian, they invested almost $1 billion in AV technology in 2019 and "expect to continue to invest, substantial amounts" (Uber, 2019, p.23). Furthermore, General Motors (GM) teamed up with Lyft to develop an autonomous taxi service (Bischoff & Maciejewski, 2016). Daimler and Bosch also agreed on jointly driving forward the development of fully automated and driverless driving and started a pilot project for robotaxis in Silicon Valley (Daimler, 2017, 2019). However, robotaxis do not necessarily have to be offered by a fleet operator. If a privately-owned AV is not in use, there is also the possibility of peer-to-peer offers by making the vehicle accessible to other people for a small fee (Lenz & Fraedrich, 2016). Tesla, for example, promotes a fully autonomously driven future in which its customers participate in a peer-to-peer autonomous Tesla ride-hailing network (Tesla, 2019).

3. Methodology

The following chapter describes the methodology to answer the research questions of the underlying work. First, the research design is introduced. Second, the data collection process, consisting of primary and secondary research, is elaborated.

3.1 Research design

Following the example of various researchers investigating the impact of robotaxis on the passenger transportation industry (F. Becker et al., 2016; Hörl et al., 2016), the underlying research uses an exploratory research design. It focuses on investigating possible changes in consumers' mobility behavior arising from the introduction of robotaxis and examines the most likely state of the industry five to ten years from now.

A qualitative research approach is chosen to enable an in-depth analysis of the investigated research topic and provide an answer to RQ1, "*What is the impact of robotaxis on the European passenger transportation industry?*". Since robotaxis and SAE level 5 autonomous driving previously only appeared in hypothetical mobility concepts and design studies, no precise quantitative data or fact-based findings have been generated yet. Therefore, application-oriented research and an explorative approach is necessary to identify possible impacts of robotaxis on the passenger transport industry. Based upon the gathered qualitative components, a semi-quantitative method of estimation is used to identify the use case with the highest application potential for robotaxis. An evaluation model is developed whereby predefined parameters are assessed on a five-point scale using both primary and secondary data. Contributions from stakeholders are weighted based on their influence and importance for the adoption of robotaxis. The use cases of robotaxis are illustrated and ranked according to the weighted average of their relevance. The use case with the highest application potential is then analyzed in detail to determine the impact on the industry and provide an answer to RQ1.

To reach a conclusion on RQ2, *"How will the future path of the European passenger transportation industry look like in five to ten years from now?"*, a scenario analysis is carried out. The scenarios are constructed in analogy to the strategic scenario planning tool of Schoemaker (1995) and assume three different stances that differ in the speed of adoption with which robotaxis are introduced to the industry. The first scenario describes a "worst-case scenario" and predicts no adoption beyond the current status of robotaxis. The second scenario envisages the gradual introduction of self-driving taxis, while the third scenario foresees a "best-case scenario" and predicts the full adoption of robotaxis. The likelihood of occurrence of scenarios is adjusted based on stakeholders' reactions to past industry disruptions, insights from primary data collection, and extensive analysis. The outcome describes the most likely state of the industry five to ten years from now. The method employed was appropriate for the dissertations given time constraints and provided a simplified way to assess how the industry will look like in the future.

3.2 Data collection

3.2.1 Primary data

The primary data collection is based on semi-structured expert interviews and a consumer survey. The expert interviews were conducted with seven experts to gain an in-depth industry understanding and examine the relationship among market players to assess the impact of robotaxis on the passenger transportation industry. Semi-structured interviews are well suited for the underlying research as they allow the interview to be directed in different directions to further develop specific topics (Galetta & Cross, 2013). The sample consists of relevant stakeholders with sufficient industry background and expertise in autonomous driving technology. All interview participants have more than two years of industry affiliation and vary in their professional roles to obtain different perspectives on the respective research topic. Table 1 presents an overview of the interview participants.

Table 1*:* Overview of interview participants

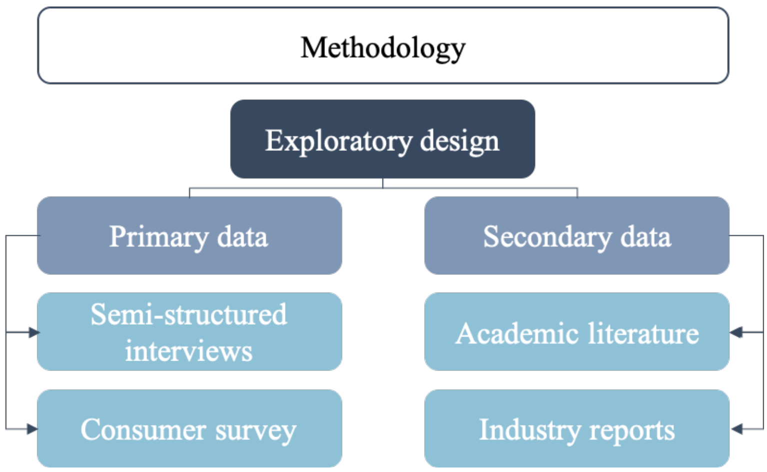
Interview	Profession	Expertise	Company description
A	Head of Corporate Strategy	Corporate Strategy	USA-based e-mobility start-up (OEM)
B	Research Associate	Vehicle concepts for autonomous vehicles	Institute of Automotive Technology at a leading German technical university
C	Concept Engineer	Use case-based vehicle concepts	Globally operating OEM
D	Trend Manager	Customer Insights & Foresights / Mobility Transformation / Trend Management	Globally operating OEM
E	Research Expert	Mobility solutions	European e-mobility start-up
F	Senior Innovation Consultant	Partnerships & Innovation	Research & Innovation center of a globally operating OEM
G	Innovation Manager	Smart vehicle concepts and innovation management	Research & Innovation center of a globally operating OEM

The questionnaire-based consumer survey includes 29 questions and analyzes the consumer acceptance for robotaxis by examining decision factors for mobility alternatives, the general interest in using robotaxis, and the potential frequency of use for each use case. In that context, acceptance means that consumers expressed their intention to use such a vehicle in the future. The sample included 102 observations and took into account the demographic parameters, gender, age, place of residence, occupation, nationality, and income. The sample is slightly skewed to European young professionals and students. From 102 observations, 16 observations with missing data were excluded. The survey was distributed via online community forums and social media platforms. An overview of the sample and survey questions is shown in Appendix E.

3.2.2 Secondary data

Secondary data mainly consists of existing academic literature and relevant industry reports written by research centers, top tier consulting firms, or investment banks. An overview of the relevant literature is given in the literature review in chapter 2. Additional reports and renowned sources are consulted throughout the analysis on an as-needed basis. Figure 1 illustrates an overview of the methodology of the underlying research.

Figure 1: *Methodology overview*



4. Analysis and discussion

Existing literature has acknowledged the concept of robotaxis as a possible disruptive force for the passenger transportation industry (Ambadipudi et al., 2017; Lang et al., 2016; Stegmüller et al., 2019). However, the full extent of its impact is still subject to a degree of uncertainty.

The following chapter determines the impact of robotaxis from a consumer perspective. First, a brief overview of possible use cases for robotaxis is made. After evaluating them in terms of their market potential and implementation complexity, the use case with the highest application potential is then selected to further investigate the impact of robotaxis in detail. Subsequently, a scenario analysis defines the future path of the industry in five to ten years.

4.1 The impact of robotaxis on the passenger transportation industry

4.1.1 Use cases of robotaxis

Higher automation levels can significantly change the consumers' mobility behavior for explicit trips (Trommer et al., 2016). As robotaxis require the highest level of automation, the underlying research concentrates only on use cases for SAE level 5 AVs. Moreover, the work segments the use cases according to the societies everyday mobility needs and the environments in which robotaxis may operate.

The necessity to segment use cases by mobility needs is driven by the different opportunity costs associated with each mobility need (Interview A, Interview E). Mobility needs only change slightly over time and arise from a person's desire to change location (Ammoser & Hoppe, 2006, Interview B). Based on the work of Tully and Baier (2006) and the central statistical survey "Mobility in Germany" by the BMVI (2019), the underlying research made a simplified subdivision of mobility needs into "Work and Education" and "Leisure activities".

Furthermore, the necessity to subdivide use cases according to the operating environment is driven by the technological requirements for robotaxis' implementation. The ease of robotaxis' implementation varies considerably depending on the road infrastructure and the diversity of road users (Interview C). The complexity of implementation for an operating environment can be recognized by the likelihood of the occurrence of unforeseen traffic situations. For AVs, these unforeseen traffic situations are called edge cases. Operating environments with a higher number of edge cases typically require more advanced technology (Interview B). Considering this, a deviation of use cases into three operating environments, urban, suburban, and intercity, is made. Use cases assigned to urban areas are short inner-city trips requiring a high degree of technology to cope with the high variety of traffic situations and diverse road users (Interview

E). Suburban use cases demand less complex autonomous technology requirements, as there are fewer potential edge cases for medium distance trips (Interview B). Intercity use cases are long-distance trips on the highway, which require the lowest degree of technological development among all presented operating environments (Interview B). The underlying research does not consider rural areas as robotaxis would potentially have low penetration rates, and therefore the lowest economic use (Interview G). Since SAE Level 5 robotaxis can operate in a mixture of traffic environments, each use case is allocated to its predominant operating environment.

All subsequent use cases are identified based on expert interviews, existing academic literature, and relevant industry reports. Table 2 illustrates a list of five use cases related to the mobility need "Work and Education", while table 3 displays a list of six use cases related to the mobility need "Leisure activities". Both tables represent non-exhaustive lists of car-based trips.

Table 2: *Non-exhaustive list of use cases for the mobility need "Work and education"*

Operating environment	Use case
Urban	Family rides (e.g. bringing kids to school)
	Rides for business purposes (e.g. meeting, workshops, etc.)
Suburban	Work-related commuting
	Transportation to airport or train station
Intercity	Work-related long-distance trips (e.g. by sales representatives)

Table 3: *Non-exhaustive list of use cases for the mobility need "Leisure activities"*

Operating environment	Use case
Urban	Shopping/Errands
	Recreational trips (e.g. restaurant visits, gym, etc.)
Suburban	Weekend or day trips to nearby cities
	Accessibility to city centers
Intercity	Vacation trips
	Shared long-distance trip

4.1.2 Evaluation model

The underlying research employs a scoring model that consolidates and evaluates the information gathered from the consumer survey, the expert interviews, and existing literature to systematically evaluate the use cases. For the evaluation, the latest data from the Federal Statistical Office of Germany (Destatis) is used as a proxy for the European market. German data is used, as Germany is one of the leading European countries in readiness for autonomous vehicles (KPMG, 2019), and European data availability is limited. The use cases are assessed on a five-point scale according to the weighted average of their market potential and ease of implementation.

<u>Market potential</u>

When assessing the market potential of the use cases, three evaluation criteria are decisive, the use case size, the added value of robotaxis, and the consumer acceptance, which displays the consumers' willingness to use robotaxis for each use case (Interview A, Interview B, Interview E).

The size of each use case describes the addressable market of robotaxis and is indicated by the cumulated number of rides per year, adjusted to the five-point scale. The size is determined on use case specific characteristics, and calculations are based on the latest German data. The second criterion examines the added value of robotaxis compared to other means of transportation. The assessment was made through the inclusion of expert opinions. Lastly, the consumer acceptance describes the level of acceptance and the prospects for use for robotaxis. It considers any mental reservation a consumer might have and is investigated by the questionnaire-based consumer survey.

The market potential of the use case is based on the weighted average of the three criteria. Since the underlying research investigates the impact of robotaxis from a consumer perspective, the consumer survey results were weighted with 40%, while the use case size and the added value by robotaxis were each weighted with 30%. A detailed evaluation of the criteria can be found in Appendix B.

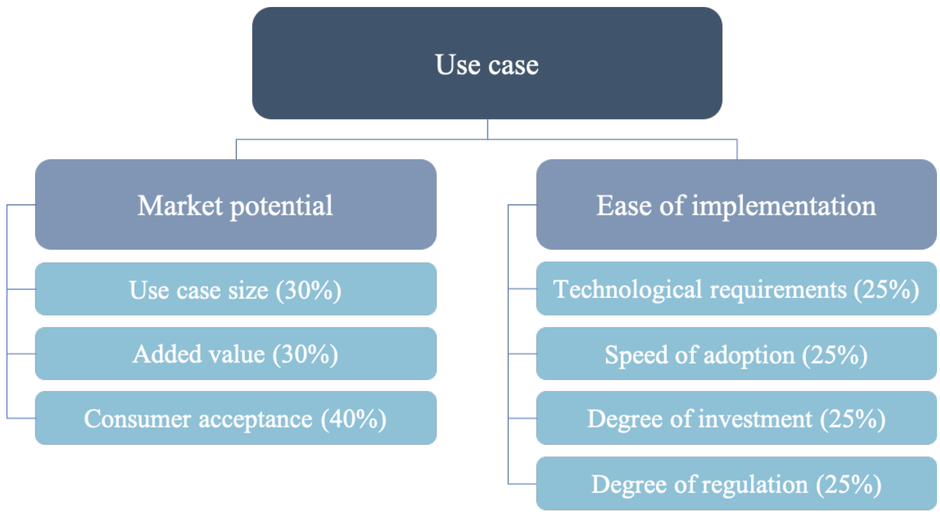
<u>Ease of implementation</u>

Since a robotaxi is deemed a disruptive innovation with far-reaching impacts on the passenger transportation industry, the implementation complexity of robotaxis must also be considered when evaluating use cases. Therefore, the ease of implementation is evaluated by analyzing four factors.

First, the technological requirements evaluate the technology's maturity in light of SAE level 5 autonomous driving for the particular use case. Use cases with a higher number of edge cases require more significant technological development (Interview B). Second, the speed of adoption evaluates the use case-specific likelihood of how quickly robotaxis will be ready for operation within the next five to ten years. Among other parameters, the deployment of infrastructure, safety requirements, and technology's current state play a decisive role. Third, the degree of investment assesses how much companies need to invest in introducing robotaxis for a concrete use case. This is linked to the current state of technology. Lastly, the degree of regulation assesses the extent to which the governments and municipalities are likely to regulate the passenger transportation market for each use case.

All four criteria are equally weighted and are highly dependent on the use cases operating environment. They are assessed through the inclusion of expert opinions and relevant existing literature. Figure 1 illustrates an overview of the evaluation criteria.

Figure 2: *Evaluation criteria for the assessment of use case potential*



4.1.3 Assessment of use cases

Although both evaluation criteria are decisive for examining the high potential use case for robotaxis, the underlying study uses a different weighting of their importance. Validated by industry experts, the market potential is weighted at 80%, and the ease of implementation at 20%. From an economic standpoint, use cases with high market potential are more attractive than those with low market potential. Hence, they are more likely to be implemented by companies. From that, it can be inferred that companies' willingness to implement use cases decreases with declining market potential (Interview D). In addition, high market potential is associated with high consumer demand, which leads to a higher potential impact of robotaxis. However, it should be noted that the implementation of robotaxis for applications with low market potential is not ineffectual.

Table 4: *Use case evaluation and ranking*

Use case*	Mobility need	Operating environment	Market potential (80%)	Ease of implementation (20%)	Overall rating (WA)
Work-related commuting	Work and Education	Suburban	4.30	3.00	**4.04**
Recreational trips (e.g. restaurant visits, etc.)	Leisure activities	Urban	4.03	2.50	**3.72**
Transportation to airport or train station	Work and Education	Suburban	3.58	3.50	**3.56**
Accessibility to city centers	Leisure activities	Suburban	3.41	3.50	**3.42**
Shopping/Errands	Leisure activities	Urban	3.51	2.50	**3.31**
Rides for business purposes (e.g. meetings, workshops etc.)	Work and Education	Urban	3.48	2.50	**3.28**
Family rides (e.g. bringing kids to school)	Work and Education	Urban	3.37	2.50	**3.20**
Work-related long-distance trips (e.g. by sales representatives)	Work and Education	Intercity	2.98	4.00	**3.19**
Weekend or day trips to nearby cities	Leisure activities	Suburban	2.37	3.50	**2.60**
Shared long-distance trips	Leisure activities	Intercity	2.16	4.00	**2.53**
Vacation trips	Leisure activities	Intercity	1.98	4.00	**2.38**

*not exhaustive

The use cases in the table above are arranged in descending order according to the weighted average of their market potential and ease of implementation. Table 4 shows that only one use case has a score above four, while seven use cases have a score above three, and three use cases have a score above two. As there is only one use case with a score above four, it can be inferred that the results partly reflect the reluctance of consumers towards robotaxis. This is not surprising as robotaxis had previously only appeared in the form of hypothetical concepts and design studies, and the evaluation components of the market potential include the consumers' opinion.

Furthermore, with exceptions, the outcome shows that use cases with lower market potential tend to be easier to implement. The reason for that is the correlation between the ease of implementation and the operating environment. The interviewees argued that urban areas are the most challenging operating environment for implementing robotaxis, as the vehicles are confronted with a large number of diverse road users (Interview B; Interview C). In this context, suburban areas pose a medium challenge, and intercity travel a small challenge for implementing robotaxis (Interview B).

Although the implementation of robotaxis in urban and suburban areas seems complex, it is equally promising. Due to the population density and expected demand, robotaxis tend to have a high market potential when operating in such conditions. According to the industry experts, the application of robotaxis in urban or suburban environments could complement current transportation means to improve the existing transport system and add value to the current mobility supply. (Interview G). In contrast, robotaxis operating in intercity use cases could compete with existing means of transportation and are expected not to add significant value (Interview B).

For investigating the impact of robotaxis on the passenger transportation industry, this work solely takes the use case with the highest application potential into account, work-related commuting.

4.1.4 Impact of high potential use case

In the light of work-related commuting, the following chapter identifies multiple insights on the impact of robotaxis on the passenger transportation industry. In particular, a possible change in consumers' mobility behavior is investigated by exploring the impact on the consumers' value of time and monetary costs. This is followed by a qualitative analysis of the robotaxis impact on the industries competitive landscape, new revenue streams, and infrastructure.

4.1.4.1 Value of personal travel time

The value of personal travel time refers to the cost of time spent on transport (travel time costs) and expresses the willingness to pay for travel time reductions (Litman, 2020b). It has to be understood as a valuation of travel time savings, which "refers to the benefits of faster travel that saves time" (Litman, 2020, section 5.2, p. 2). The valuation of personal travel time can differ depending on the circumstances of the trip (Trommer et al., 2016). Therefore, the time pressure when rushing to an important event is higher than when driving to a nearby city at the weekend. Hence, the willingness to pay for a travel time reduction is lower in the second situation (Trommer et al., 2016). The travel time costs are computed through the product of time spent traveling and the unit costs (euro per minute) (Litman, 2020).

$$Travel\ time\ costs = Time\ spent\ traveling\ \times\ Unit\ costs\ (euro\ per\ minute)$$

According to Litman (2020), the unit costs are usually estimated at 25% to 50% of prevailing wages and are dependent on the type of trip, the travel conditions, traveler preferences, and the modes of transport (Litman, 2020; Trommer et al., 2016). In the underlying research, the type of trip and the travel conditions are characterized by the particular use case, while travelers' preferences are assumed to be identical for the investigated user group. As European data for calculating travel time costs is limited, the data is extracted from federal offices of Germany, as they represent a valid proxy for determining the impact of robotaxis on European passenger transport. Therefore, the findings should be considered as indications rather than exact measures of a European commuters travel time costs.

Value of time: Commuting by private car

Since work-related commuting is a crucial determinant of peak traffic, many commuters are regularly stuck in traffic jams or witness overcrowded public transportation, especially in urban and suburban areas (Trommer, 2016). Driving in congestion or travel in uncomfortable conditions are considered driving conditions in which travelers experience significant discomfort or frustration. These conditions are suggested to account for 50% or more of the travelers prevailing wages (Litman, 2020). Compared to unemployed people, commuters are expected to be more sensitive to the time spent traveling because of a stronger sense of limitation of their time budgets (Trommer, 2016). Additionally, this user group is identified as having a fairly high purchasing power (Interview D). Hence, it seems reasonable that their willingness to pay for a travel time reduction is higher than for other user groups.

The average net disposable income for a German employee is €2.079 per month (€0.22 per minute) (Destatis, 2020b) and serves as a proxy for the European net disposable income, once adjusted for purchasing power parity (PPP). Under the conditions of peak traffic, the unit costs for a private car are estimated at 50% of commuters' prevailing wages, following the suggestions of Litman (2020). Therefore, the unit costs for commuting by car amount to €0.11 per minute. In terms of time spent traveling, German employees commuted to their workplace for an average of 44 minutes (Giménez-Nadal et al., 2020). However, as this represents the average commuting time over all transportation means, it is necessary to distinguish between the commuting time by a private car and by public transportation. Since the time saving for someone who takes the private car is usually higher than for someone who uses public transport (Deutsche Bank, 2019), an average commuting time of 35 to 40 minutes (incl. parking) for the private car is assumed. Therefore, the value of time can be determined as follows:

$$Travel\ time\ costs = 35min\ to\ 40min\ \times\ 0{,}11€/min$$

$$Travel\ time\ costs = €3.85\ to\ €4.40$$

The calculation shows that the value of time for a 35- to 40-minute commute by private car ranges from €3.85 to €4.40. Hence, a private car commuter is willing to pay €3.85 to €4.40 for a time saving of the entire travel duration.

Value of time: Commuting by public transportation

Similar peak traffic conditions can be assumed for commuting by public transport. In this case, commuters are not stuck in traffic jams, but they are exposed to overcrowded public transportation. To account for crowding, the travel time for public transportation is therefore estimated at 50% of commuters' prevailing wages, following Litman's (2020) suggestions. Furthermore, the actual travel time takes more minutes per trip than in the previous case (Litman, 2020). Based on estimates of the Litman (2020), the underlying research assumes that public transit will take on average about 10 minutes longer compared to private cars. The additional time can be attributed to the time spent waiting and walking to the transport station. Since employed people have a strong sense of limitation to their time budgets and might perceive waiting or walking time as "wasted" (Trommer et al., 2016), the unit costs are considered to be 100% of the prevailing wages, following the suggestion of Litman (2020) again. Based on the assumptions made, the travel time costs for public transportation can be calculated as follows:

$$Travel\ time\ costs_{in-vehicle} = 35min\ to\ 40min\ \times\ 0.11€/\min = €3.85\ to\ €4.40$$

$$Travel\ time\ costs_{waiting\ \&\ walking} = 10min\ \times\ 0.22€/\min = €2.20$$

$$Total\ Travel\ time\ costs = €6.05\ to\ €6.60$$

The value of time for a 45- to 50-minute commute by public transportation ranges from €6.05 to €6.60 and is higher compared to the value of time for a private car.

Value of time: Commuting by robotaxi

It is expected that autonomous vehicles will significantly reduce the value of travel time, since the occupants would benefit from the opportunity to relax or engage in other activities (Fraedrich et al., 2016). Although the actual time spent in traffic is not expected to decrease at an early stage of adoption, traffic time may no longer be perceived as "wasted". That is particularly relevant for the investigated user group as employed people have a stronger sense of limitation to their time and can now spend time in a more "meaningful" way (Trommer et al., 2016). Therefore, the travel time for a robotaxi is assumed to be 25% of commuters' prevailing wages. The travel time costs for commuting to the workplace by a robotaxi is calculated as follows:

$$Travel\ time\ costs = 35min\ to\ 40min \times\ 0.06€/min$$

$$Travel\ time\ costs =\ €2.10\ to\ €2.40$$

The value of time for commuting by robotaxi is the lowest compared to the other means of transport investigated in this study. They are predicted to range from €2,10 to €2,40. Table 5 provides an overview of the commuters' value of time by mode of transportation.

Table 5: *Value of time for commuting by mode of transportation*

Mode of transportation	Actual travel time in min	Unit costs in €/min	Value of time in €
1. Robotaxi	35 to 40	0.06	**2.10 to 2.40**
2. Private car	35 to 40	0.11	**3.85 to 4.40**
3. Public transport	45 to 50	0.11 & 0.22	**6.05 to 6.60**

The results in Table 5 should be considered in the light of the assumptions made in the underlying research. The advent of robotaxis significantly reduces the value of time for work-related commuting, since they can change the individual perception of travel time by enabling effective use of time and increasing comfort. Compared to other means of transportation, the willingness to pay for a reduction in travel time is, therefore, significantly lower when using a robotaxi. From this, it can be interpreted that the consumers' willingness to pay for a robotaxi is higher than for the other transportation options investigated in the analysis. The results are in line with the opinions of experts who stated that robotaxis are perceived as more time efficient, as the in-vehicle time can be used effectively when the driving task is omitted (Appendix D).
Since the survey results indicated that time efficiency is the most critical factor for consumers when choosing between means of transportation, it can be inferred that robotaxis will

dramatically impact the consumers' mobility behavior (Appendix E). The benefits of pursuing other activities while traveling and, simultaneously, benefitting from the advantages that a car provides raises the hypothesis that the advent of robotaxis can lead to a significant shift in consumer preferences in passenger transportation once they gain market share in Europe. Furthermore, people might consider traveling longer distances as the in-vehicle time is not perceived as "wasted" anymore and can be spent in a more "meaningful" way (Trommer et al., 2016). The impact on the value of time can be even more significant once robotaxis attain a substantial adoption rate. In that case, they are supposed to reduce actual travel time by making traffic flow more efficient and causing less congestion (Interview G).

4.1.4.2 Monetary costs for commuting

In the previous chapter, the hypothesis was raised that the advent of robotaxis leads to a significant shift in European consumer preferences in passenger transportation. However, to draw a comprehensive conclusion on a possible change in consumers' mobility behavior, one must also consider the monetary costs. The monetary costs indicate whether the use of robotaxis is price competitive with other means of transportation. If the costs are too high, it is unlikely that robotaxis will be used in the future. Since medium-sized cars are one of the most sought-after vehicle types in Europe (Statista, 2020), an analysis of existing literature is carried out to examine the costs per kilometer for such privately-owned cars. To ensure comparability with previous findings, German data was consulted when necessary. Thus, conclusions can be drawn for the European market, when the monetary costs are adjusted to country specifics. The following formula shows how the monetary costs of the means of transportation are calculated.

$$Monetary\ costs = Avg. Distance\ in\ km\ \times\ Costs\ in\ €\ per\ km$$

Monetary costs: Commuting by private car

Private cars' costs depend on various factors and are divided into operating costs and ownership costs. Operating costs usually include costs for fuel, maintenance, and tires, while ownership costs include costs for insurance, registration, depreciation, and financing (VTPI, 2017). Existing literature serves a fragmented picture regarding the costs per kilometer for a private car. The investment bank UBS (2017) calculates the cost per kilometer for a private car at around €0.60 per kilometer. In comparison, the American Automobile Association (AAA)

(2019) estimates the cost at $0.75 per mile (€0.40 per kilometer).[1,2] On the other hand, Bösch et al. (2018) calculates costs of 0.48 CHF per kilometer (€0.44 per kilometer).[3] An identical estimation was made by Deloitte (2019). Since the costs per kilometer may vary due to different calculation methods and consideration of calculation parameters, the underlying research estimates a cost range of €0.40 to €0.60 per kilometer. However, it needs to be mentioned that the costs may vary depending on the vehicle type and the number of kilometers traveled. As on average, the distance of work-related commuting in Germany amounts to nearly 17 kilometers (Götz, 2017), the monetary costs for commuting by a private car are between €6.80 and €10.20. However, the results should be viewed critically, as some European countries provide compensation for travel-to-work expenses. These compensations are sometimes included in general work-related deductions (e.g., in France or Italy) or designed as commuter tax allowances (e.g., Germany, Netherlands, Denmark) (Paetzold & Winner, 2016).

Monetary costs: Commuting by public transportation

The monetary costs of commuting by public transportation depend solely on the ticket costs for the user. Ticket costs vary by route and depend on whether it is a one-way, daily, or monthly ticket. In addition, ticket costs may differ between countries and cities. As European data for public transportation costs are limited, the present research assumes a ticket price of €60 to €90, as the average price for a monthly ticket in Germany is about €77.50 (ADAC, 2019). Using the price for a monthly ticket seems plausible, as it tends to be the cheapest option for daily commuting. Therefore, the ticket price per day ranges from approximately €2 to €3. Since public transportation users in Germany travel about 30 kilometers a day (BMVI, 2019), the cost per kilometer ranges from nearly €0.07 to €0.10. In conclusion, the monetary costs for work-related commuting by public transportation are estimated to range from €1.19 to €1.70. Hence, public transportation is significantly cheaper than a private car.

Monetary costs: Commuting by robotaxi

For the costs per kilometer of a robotaxi, again, existing literature serves a fragmented picture. While UBS (2017) estimates the kilometer price for an autonomous taxi to be €0.40, Deloitte (2019) expects it to be €0.34. Bösch et al. (2018), on the other hand, predicts the kilometer price for robotaxis to be €0.38. These results are in line with Chen's financial analysis (2015), which

[1] Exchange rate: 1,1760 $/€
[2] 1 Mile = 1,60934 Kilometer
[3] Exchange rate: 1,08 CHF/€

concluded that the price of a fleet operated autonomous vehicle is between €0.35 and €0.41. Some studies estimated even lower costs. For example, Arbib and Seba (2017) predicted that robotaxis would cost less than €0.10 per kilometer. However, such predictions seem to be underestimating the amount as they ignore costs such as cleaning, repairs, insurance, and margins. Therefore, the underlying research uses a price range comparable to Chen (2015) of €0.34 to €0.41 per kilometer. The monetary costs for work-related commuting by robotaxi are estimated at €5.78 to €6.79. Table 6 outlines the results of this chapter.

Table 6: *Monetary costs of commuting by mode of transportation*

Mode of transportation	Avg. commuting distance in km	Costs in € per km	Monetary costs in €
1. Public transport	17	0.07 to 0.10	**1.19 to 1.70**
2. Robotaxi	17	0.34 to 0.41	**5.78 to 6.79**
3. Private car	17	0.40 to 0.60	**6.80 to 10.20**

The findings should be viewed critically as the price for the end consumer is conditional on the vehicle type, the business model, and pricing decisions of the companies (Interview D). Nevertheless, the outcome allows the conclusion that the cost per kilometer of robotaxis will be competitive compared to private cars. As a result, consumers are likely to switch from private cars to robotaxis as they can engage in other activities and simultaneously benefit from the advantages that a private car provides (Trommer et al., 2016). In addition, the reduction in the importance of the car as a status symbol rules in favor of the robotaxi (Interview B).

For public transportation, it can be concluded that relative prices are increasing, although it remains the cheapest transport option among the modes considered in this work. It can be expected that for some consumers the high travel time costs outweigh the monetary cost savings and may foster a shift in consumer preferences towards robotaxis. Since the survey results showed that the price is a secondary factor in the transportation option choice (Appendix E), it can be inferred that primarily price elastic consumers use public transportation. Once robotaxis reach a significant penetration rate and competition increases, prices are expected to drop further, and robotaxis might also become attractive for public transportation users (UBS Investment Bank, 2017; Interview D). Therefore, the cost competitiveness of robotaxis supports the hypothesis made in the previous chapter; the advent of robotaxis may lead to a significant shift in consumer preferences in passenger transportation. However, it should be mentioned that regardless of the extent to which consumers' mobility behavior changes, there will always be demand for public transportation and private cars (Interview B).

4.1.5 Shift in consumer preferences

Previous analysis has revealed that the impact of robotaxis on the value of time and the monetary costs potentially lead to a change in consumers mobility consumption patterns. In particular, it was hypothesized that the advent of robotaxis may lead to a significant shift in consumer preferences in passenger transportation. The following chapter analyzes the influence of robotaxis on consumer preferences regarding the choice of transportation modes. For the purpose of this analysis, again, European data is not sufficiently available, and German data is used as a proxy to represent changes in European consumer preferences. The analysis mainly focuses on the demand side and investigates the potential shift in consumer preferences from a consumer perspective.

Today, there are around 19.3 million commuters in Germany. Some 12.9 million (67%) German employees commute by private car, while 2.7 million (14%) use public transportation and 3.7 million (19%) other transport options, such as cycling and walking (Destatis, 2017). It is assumed that people who walk or cycle to their place of work are unlikely to change their mobility behavior as they tend to live close to their workplace. However, private car and public transportation users are likely to change their mobility behavior (Interview A).

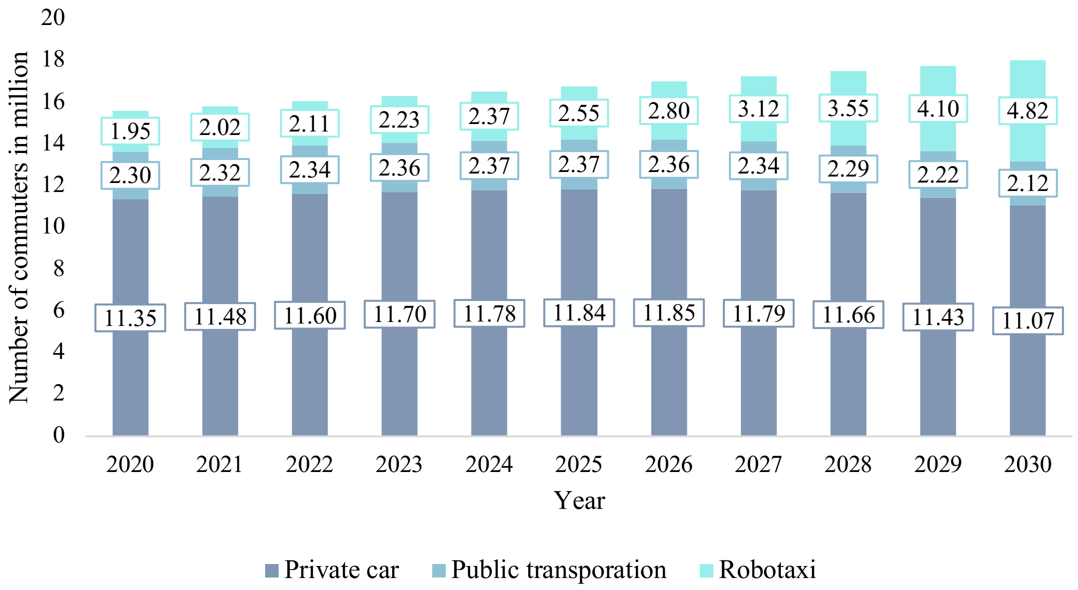
The survey results of the present research revealed that about 56% (10/18) of employees who regularly commute with a private car and 57% (4/7) commuters who frequently use public transportation are willing to use a robotaxi instead (Appendix E). Since the number of survey participants is too small to guarantee valid data, more conservative switching rates are used to illustrate the shift in consumer preferences. This seems reasonable, as industry experts argue that the adoption of robotaxis can be illustrated by a sigmoidal curve (S-shaped curve), which is mainly due to the further development potential of the technology and consumers increasing trust in technology (Interview D).

Other studies came to more conservative conclusions. Fraedrich et al. (2016) infers that about 26% of people are willing to replace their currently preferred transportation option with a robotaxi. Deloitte (2019), on the other hand, specifies the results and concludes that about 15% of employed car users and 12% of employed public transportation users are willing to switch to a robotaxi in the upcoming years. Additionally, Winkeler et al. (2019) infers that the consumer preferences towards self-driving cars will increase over time. They investigated that currently, 17% of Germans would be willing to replace their currently preferred transportation option with a self-driving car. Further, they conclude that this number is set to double in the next five years.

As the results depicted by Deloitte (2019) best fit the use case considered in the underlying research, they are leveraged to illustrate the shift in consumer preferences. Moreover, the findings of Winkeler et al. (2019) are used to illustrate an exponential growth of potential switching rates towards robotaxis. The exponential growth in switching rates can be explained by cost reductions and the increasing acceptance of autonomous technology over time (Winkeler et al., 2019). After validation with industry experts, the underlying research therefore assumes an annual increase in switching rates of 1% until 2025 and 2% after 2025. Illustrations of the switching rates for private car and public transportation commuters are attached in Appendix C. Additionally, it is assumed that the commuter rate follows its historical trend. Thus, the future commuter rate is predicted by applying the CAGR 2000 - 2018, which accounts for 1.45%.

Figure 3 forecasts the potential shift in consumer preferences towards robotaxis of commuters who regularly travel to work by private car or public transportation over a ten-year period.
It is displayed that already today, 1.95 million commuters are willing to use a robotaxi even they do not yet exist. Figure 3 illustrates that in five years from now, more employees are willing to commute by robotaxi than by public transportation. Apart from that, it is displayed that in ten years, about one-fourth of consumers are willing to commute by robotaxi. Figure 3 showcases a significant transformation in European consumers mobility behavior and confirms the hypothesis established in the previous analysis. The outcome is also consistent with the information provided by industry experts, who stated that private vehicles and public transport are becoming increasingly unattractive as they no longer have an advantage over robotaxis (Interview A; Interview B).

Figure 3: *Consumer preferences of German commuters*



This outcome should be viewed critically, as it is based on a simplified analysis in which only the demand side is considered. Therefore, the results do not reflect an effective modal shift but rather display the willingness to use robotaxis. To examine the potential modal shift through the advent of robotaxis, it is also necessary to consider the supply side. This would require information about the penetration rate, vehicle utilization, business models, the progress in government regulations, technology, and other parameters. As these factors are subject to a high degree of uncertainty, the underlying research chose not to focus on them. Nevertheless, regardless of not showcasing a quantitative analysis of a potential modal shift, industry experts confirm that "a dramatic modal shift will occur when robotaxis achieve significant rates of adoption and consumers gain trust in the technology" (Interview D). Since this expectation presumes major technological and regulatory progress, there is consensus among industry experts that a dramatic modal shift will not occur until 2040. Moreover, the results should be considered neither exhaustive nor exclusive but rather serve as an indication and confirm the previously made hypothesis.

4.1.6 Additional factors

<u>Impact on the industries competitive landscape</u>

Robotaxis may lead to a fundamental change in the automotive industry's existing power structure (Interview A). By investing heavily in autonomous driving technology and forming strategic partnerships with technology firms, shared mobility providers and mobility start-ups, automotive incumbents are trying to establish a leading position in the changing market environment (Interview A; Interview D; Modi et al., 2018). Increasing competition and the ever shorter response time to technological changes lead to a hypercompetitive and fast-moving environment in which firms find it harder to achieve long-term competitive advantage (Interview A; Barreto, 2010). Therefore, from a managerial perspective, it needs to be emphasized that a firm's survival depends highly on the focal firms' dynamic capabilities to respond to industry disruption and external shocks (Interview C; Barreto, 2010). Interviewee A expressed that "In the long-term there will be many setbacks and unexpected bankruptcies for some companies in the industry, partly due to robotaxis.". Additionally, the advent of robotaxis will force collaborations between industry players, opening new sources of income (Interview G). The emergence of robotaxis will, therefore, significantly impact the competitive landscape of the passenger transportation industry.

<u>New revenue streams</u>

The advent of robotaxis can be an opportunity for existing market players, since the value chain will alter, and new business models arise (Interview D). With the introduction of robotaxis, industry experts expect five sources of income: Hardware, Software, Fleet management, Service (Content), and Data management (Interview D). While the hardware (powertrain, chassis, interior) will presumably continue to be provided by OEMs (Interview F), the software will likely be provided by established technology companies or start-ups (Interview D). As the software becomes a crucial part of a robotaxi, some OEMs will vertically integrate autonomous technology development by acquiring firms with sufficient expertise (Interview F). Fleet management is acknowledged as an essential part of the seamless operation of robotaxis and will become increasingly relevant (Interview E). Currently, shared mobility services are leading in this area. Collaborations can, therefore, be expected (Interview E). Additionally, changes in the mobility behavior of users should be seen as an opportunity. Experts suspect that "OEMs are already trying to position themselves as service providers." (Interview E). Consequently, car manufacturers will offer a range of services in the future. One of them will be in-vehicle content, which can presumably be served by collaborations with entertainment providers. Interviewee D stated that in order to generate revenue, "OEMs will collaborate with entertainment providers such as Netflix and charge a premium for allowing them to offer its services in their car." Ultimately, data management is seen as one of the most important income sources, as "OEMs will focus less on operations and more on the reuse of consumer data and the targeted placement of content in the vehicle" (Interview E). Additionally, data management could stimulate the conventional sales and after-sales business by making targeted offers to consumers (Interview D). Although there is consensus among industry experts that robotaxis will create new sources of income and significantly change how industry players generate revenue, it is still uncertain which business models will arise (Interview B).

Impact on infrastructure

Robotaxis also have a substantial influence on urban structures and infrastructure. For a long time, experts had the opinion that the infrastructure should be changed as little as possible, since European city centers are often historical (Interview E). This view has changed. Today, there is a growing consensus that infrastructure must have specific capabilities to ensure rapid implementation of robotaxis (Interview E). Therefore, the infrastructure is to be equipped with sensors and cameras in order to be able to take over the guidance of vehicles and provide technological support (Interview E). Moreover, the advent of robotaxis will possibly change the urban street scene in the long term, as parking spaces can be redesigned and lead to a widening of the traffic area (Interview B; Interview G). This, in turn, could lead to a reduction in congestion and make traffic flow more efficient.

4.1.7 The impact of robotaxis

The combination of qualitative analysis and quantitative indicators to measure the emergence of robotaxis has led to multiple insights on the impact of robotaxis.

The effects are illustrated by the use case with the highest application potential, work-related commuting. The findings show that robotaxis lead to a reduction in commuters' value of time and competitive pricing. This allows to derive the hypothesis that the advent of robotaxis leads to a significant shift in consumer preferences regarding transportation options. By forecasting the shift in consumer preferences, the hypothesis was confirmed. Furthermore, it was shown that the advent of robotaxis may lead to significant changes in the industry's power structure. The industry can become a highly competitive environment in which firms only survive with sufficient dynamic capabilities. It was found that five new revenue streams emerge, forcing collaborations between industry players. Moreover, robotaxis may lead to changes in the urban street scene of European cities, as infrastructure will be equipped with cameras and sensors, and parking spaces might be redesigned in the long term.

Since the impact was determined solely for the high potential use case, it is reasonable to assume that the impact goes beyond the underlying study's findings. The robotaxis' flexible employment for multiple use cases underlines the high added value for the entire transport system.

4.2 The future path of the passenger transportation industry

The second part of the analysis aims at estimating the future path of the passenger transportation industry and how it will be affected by the advent of robotaxis. Consequently, in analogy to Schoemaker's (1995) strategic scenario planning tool, three different scenarios are constructed. The scenarios assume an optimistic, moderate, and pessimistic stance that differs in the speed of adoption with which robotaxis will be introduced in the industry. Provisionally, all three possible future paths are weighted with the same likelihood of occurrence of one-third. The probability of occurrence is later modified based on stakeholders' responses to past industry disruptions, insights from primary data collection, and extensive analysis. The following chapter's outcome provides an answer to RQ2 and describes the industry's most likely state five to ten years from now.

4.2.1 Stakeholder definition

Following Schoemaker's (1995) scenario planning tool, first, market influencers, primary and secondary stakeholders are defined to determine the joint impact of various uncertainties on stakeholder groups' behavior.

4.2.1.1 Primary stakeholders

Primary stakeholders can actively drive the industry’s dynamics and are considered stakeholders whose perspective is fundamental to the underlying research. The scenario analysis investigates the behavior and future stance of four primary stakeholders.

<u>Primary stakeholder 1: Consumer</u>

Consumers are considered the central primary stakeholder in this work. They are directly affected by changes in the transport system and can actively influence how quickly new transport options will be adopted (Interview F). Additionally, they drive the economic success of the industry through their purchasing power (Interview D). Subsequent stakeholders have a vast interest in interacting with consumers to align their business models with consumer preferences (Interview C).

<u>Primary stakeholder 2: Car manufacturer</u>

The traditional car manufacturer is one of the main stakeholders in the passenger transportation industry. All its decisions have a significant impact on the future success of robotaxis. OEMs have a clear supremacy and are highly regarded in the development of cars (Interview F). Additionally, they play a significant role in satisfying consumer preferences with new vehicle concepts (Interview B). This stakeholder group drives autonomous technology development through substantial investments and is already implementing autonomous features in today's cars (ACEA, 2019). Since it is expected that the emerging autonomous technology will change the automotive paradigms (Interview A), it remains to be seen how the large OEMs will act to protect their position of power. Which actions they take depends primarily on the direction in which the industry develops.

Primary stakeholder 3: Technology company

Technology companies are leaders in developing autonomous technology and have the necessary financial resources to actively influence the speed of adoption of robotaxis (Interview C). As this stakeholder group recently entered the automobile market, competition for established market participants increased and changed the industry’s existing dynamics (Interview A). Due to high investments in autonomous technology, this stakeholder group has a keen interest in the success of robotaxis. Therefore, all their decisions have a significant influence on the development of robotaxis.

Primary stakeholder 4: Ride-hailing companies

Ride-hailing companies have a continually growing user base and invest heavily in autonomous driving technology (Uber, 2019). This stakeholder group may be a critical part of the future value chain. They have significant fleet management expertise and can leverage their user base to establish robotaxis in the market (Interview E). Additionally, they form the customer interface and represent an attractive partner for other primary stakeholders (Interview D) (Interview D). Ride-hailing companies are considered among potential early adopters that benefit from eliminating the driver as the main cost factor of their business model (Interview E)

4.2.1.2 Secondary stakeholders

Secondary stakeholders are passively affected by the advent of robotaxis and do not actively promote a change, merely reacting to changes happening around them. Although there are multiple secondary stakeholders in the passenger transportation industry, this work focuses on public transportation service providers. Dependent on the speed of adoption, different reactions can be identified concerning this stakeholder group.

4.2.1.3 Industry influencers

Industry influencers profoundly affect the speed of adoption and accelerate or decelerate the market developments towards robotaxis. In the underlying research, technology and regulation represent the leading influencers (Interview B).

4.2.2 Reaction of stakeholders to past industry disruptions

To predict the effects of robotaxis on current stakeholders, historic disruptions within the passenger transportation industry can be examined. Recent industry trends with highly disruptive characteristics have been new drive technologies and shared mobility. Although both have not reached their full potential yet, they serve as reasonable indicators on how the industry reacts to disruptive technologies. With the advent of new drive technology and shared mobility, many new companies entered the market, partly threatening established car manufacturers' predominant market position (Shipley, 2020). Therefore, the market environment became highly competitive, and the rivalry between existing market players increased. Moreover, the emergence of shared mobility has led to a modal shift and a change in consumer behavior (Rayle et al., 2016). The established car manufacturers are trying to maintain their supremacy by investing heavily in new technologies, developing new business models, and cooperating with other market players (Bagloee et al., 2016; Daimler Mobility AG, 2020; Monitor Deloitte, 2017). However, both trends show that the industry players have been reluctant to invest in the past. Therefore, they have been slow to adapt to disruptive technologies in their industry. Table 7 gives a brief overview of past stakeholder reactions to the advent of new drive technologies and shared mobility.

Table 7: *Overview of stakeholders' past reaction to industry disruptors*

Stakeholder	Disruption	Reaction
Consumer	Shared mobility	- Modal shift and change in consumer behavior (Rayle et al., 2016).
OEM	New powertrain technology and Shared mobility	- High investments and partnerships
		- New business models (Mosquet et al., 2018)
Shared mobility services	Shared mobility	- Digitalization of the customer interface (Interview D)
		- Increased competitive landscape through the rise of new companies
Technology companies	New powertrain technology	- Engagement in electric vehicle manufacturing

4.2.3 Three possible future paths

After defining the relevant stakeholders and examining their past reactions to industry disruptions, three scenarios were developed, which predict three possible future paths for the passenger transportation industry. In further analogy to Schoemaker's (1995) strategic scenario planning tool, the scenario themes are defined by assuming extreme worlds. Everything negative (no adoption of robotaxis) was put into one and everything positive (full adoption of robotaxis) into the other scenario. Starting from both extremes, a medium condition could be created. After a consistency and plausibility check, the scenarios are presented in Table 8.

High investments and development in autonomous technology might argue for a rapid adoption of robotaxis in Europe. Although this might justify the high potential of the disruptor, high regulation and country-specific technology requirements in Europe are likely to limit and restrict a rapid introduction of robotaxis (Interview C; Interview D). Based on previous stakeholder reactions to industry disruption, a medium adoption speed of robotaxis can be assumed. This also corresponds to the current approach of European OEMs, who are gradually implementing autonomous features into vehicles (Interview C). Furthermore, the interviewees emphasized that the adoption of robotaxis in Europe follows an evolutionary path (Interview C). Verified by the inclusion of experts' opinions, the probability of occurrence for the scenarios is weighted with 30% for scenario one, 50% for scenario two, and 20% for scenario three.

Table 8: *Scenario overview*

Stakeholder/ Influencer	Scenario 1– No adoption beyond current status	Scenario 2 – Evolutionary automation	Scenario 3 – Technology breakthrough
	This scenario describes a possible future in which the stakeholders do not experience any significant changes since robotaxis have not yet been introduced. Although the technology has made further progress, it does not meet the specifications for SAE Level 5 autonomous driving. The software does not comply with regulatory requirements.	This scenario envisages a possible future based on a moderate speed of adoption of robotaxis and shows an evolutionary development of automation systems. The required conditions for SAE Level 5 are only partially fulfilled. A progress in regulation through advanced technology is discernible.	Scenario 3 deals with the full adoption of robotaxis and foresees a possible future in which the industry experiences a technological breakthrough. The technological requirements for the robotaxis are entirely met, and the authorities fully approve the technology. The stakeholders involved will experience a significant change.
Primary stakeholder 1: Consumer	- Skeptical towards autonomous technology - Mobility behavior remains the same - Ownership structure remains unchanged	- Robotaxis used by early adopters with high purchasing power - Minor changes in consumers Mobility behavior - Minor changes in ownership structure	- Trust in autonomous technology - Shift in consumer preferences and Ownership structure - Continuous increase in robotaxi users
Primary stakeholder 2: OEMs	- Core business is the sale of vehicles and after sales - Heavy investments in autonomous technology - Form strategic partnerships with other stakeholders to achieve a leading position in the market	- Emergence of new revenue streams - Vertical integration of autonomous technology - Decreasing vehicle sales	- Strategically oriented as a service provider – operator of robotaxi fleet - Declining vehicle sales - Power structure of automotive industry changes drastically - Bankruptcies of established players
Primary stakeholder 3: Technology company	- No integration of holistic mobility platforms - High investments in autonomous technology and testing of robotaxis in the USA	- Emergence of new revenue streams (Software supplier) - Operation of own vehicle fleet through partnerships	- Established software supplier - Data management
Primary stakeholder 4: Ride-hailing company	- Already known sharing services remain dominant - Strategic partnerships with other stakeholders and testing in the USA	- Market entry of new competitors - Leverage existing user base to operate robotaxi fleet - Robotaxis make up for a small fraction of the vehicle fleet	- Robotaxis make up the largest share of the vehicle fleet - Increase in user numbers
Secondary stakeholder 1: Public transport service provider	- No significant change for public transport	- Regulation of the market to avoid substitution - No exploitation of synergies between robotaxis and public transport	- Robotaxis complement public transport (Synergy effects)
Influencer 1: Regulation	- Slow progress on regulations as technology has not advanced	- Medium progress regarding regulations - Authorization of autonomous technology at country level	- Full authorization of autonomous technology in Europe
Influencer 2: Technology	- No significant progress in vehicle technology - 5G extension - High costs for technology	- Continuous progress in implementable technology - Almost complete coverage of 5G - Medium costs for technology	- Required conditions for full driving automation are met - Full 5G coverage - Low costs for technology

4.2.4 Future path of the industry: Evolutionary automation

The future of the industry is most likely to be described by scenario two, evolutionary automation. In this scenario, robotaxis make up for a small fraction of the vehicles in use. They are still expensive and are likely to be used by early adopters and consumers with high purchasing power. However, they do not yet correspond to the mental schemata of European consumers. For the time being, this leads to minor changes in ownership structure and mobility behavior. Nevertheless, early adopters presumably increase the trust in the technology across countries (Winkeler et al., 2019). The moderate speed of adoption of robotaxis affects some stakeholder groups to the extent that they have not strategically positioned themselves sufficiently to benefit from the early adopters. Therefore, stakeholders are trying to create a sufficient resource base to be able to make new market choices. Consequently, strategic development and high financial strength of the stakeholders are indispensable to meet future requirements. Some OEMs are likely to vertically integrate autonomous technology development by acquiring start-up companies to operate a robotaxi fleet in the future (Interview F). Furthermore, OEMs, technology companies, and shared mobility services are engaging in further partnerships to diversify the cost burden of technology and leverage their respective expertise (Interview B). This implies that there will be a change in the industries power structure within the next ten years, even if robotaxis are not fully adopted. With moderate speed of adoption, synergy effects between robotaxis and the existing public transport system cannot be expected (Interview C). Industry experts stated that in particular, the high regulatory demand and the technological requirements of the infrastructure are preventing the full adoption of robotaxis in the next five to ten years.

4.2.5 Strategic implications for stakeholders

Stakeholders should consider cooperations with global operating service providers (e.g., Uber) to grow their user base and expand robotaxis market reach at early stage of adoption. Global oriented service providers have the advantage of operating in multiple trans-regional locations and are able to leverage their existing user base to accelerate the adoption of robotaxis. An aspect that has already been mentioned in the research field of Mobility-as-a-Service (MaaS) by Li and Voege (2017). Furthermore, robotaxis require a stronger emphasis on integrative marketing to shape customer relationships in line with company goals and familiarize consumers with the concept of self-driving cars. Also, traditional firms need to improve their dynamic capabilities to react to industry disruptions and ensure sustainable competitiveness against current and potential rivals. In particular, they need to be able to sense opportunities and threats, make timely and market-oriented decisions and change their resource base (Barreto, 2010). Lastly, firms need to decide whether to vertically integrate or outsource the development of autonomous technology to define their competitive strategy. However, this depends on the focal firm's maximum profit (Antràs & Helpman, 2004) and a sufficient strategic fit between the resources and skills of the potential parent organization and the resources, capabilities, needs, and opportunities of the potential new business (Campbell et al., 1995).

5. Conclusion

The thesis at hand identifies the impact of robotaxis on the passenger transportation industry from a consumer perspective and depicts the industry's future state five to ten years from now. The obtained insights enable industry players to derive strategic implications, target specific customers, and develop sufficient business models and vehicle concepts to ensure their competitiveness. Furthermore, the work contributes to an objective scientific, political, and social discussion on robotaxis.

The first part of the analysis identifies the impact of robotaxis on the industry and points out that the use case with the highest application potential is work-related commuting. In relation to that, the study reveals that robotaxis are competitive in terms of costs and significantly reduce the consumers' value of time. Additionally, it can be concluded that the advent of robotaxis will lead to a significant shift in consumer preferences for commuter's mobility consumption. The analysis shows that the industry becomes more dynamic as competition increases. The fast-moving environment indicates that firms can only survive with sufficient dynamic capabilities. Apart from that, the value chain will alter, and five new potential revenue streams emerge: Hardware, Software, Fleet Management, Service, and Data Management. Moreover, it can be stated that in the long-term, the urban street scene will change since parking spaces will be eliminated, and roads can be used more efficiently.

The second part of the analysis identifies the passenger transportation industry's future path in five to ten years. With three possible scenarios, firms have a wide range of possible futures to position themselves accordingly to take advantage of the unexpected opportunities that will occur with the advent of robotaxis. The research reveals that the industry's most likely future state will be a scenario in which robotaxis are gradually introduced. This scenario is described as evolutionary automation. In the next five to ten years, robotaxis will therefore make up for a small fraction of the vehicles in use but will impose significant changes in industry dynamics. Stakeholders become service-oriented, many partnerships will be established, and low entry barriers allow companies to enter the market. From that, the study derived strategic implications. Stakeholders should foster cooperation with global operating service providers (e.g., Uber) to expand the market reach and bring technology costs down. This could accelerate the speed of adoption and lead to lower prices for the end consumer. Furthermore, the implementation of robotaxis requires engagement in integrative marketing to strengthen consumer trust in autonomous technology. Apart from that, the results indicate that firms need to strengthen their dynamic capabilities to ensure their competitiveness and survival. Lastly, the findings revealed that stakeholders need to decide whether to vertically integrate or outsource parts of the value chain to define their competitive strategy.

As any academic research, the analysis and results should be recognized in the light of research limitations. Research into technical products that have not yet been finally developed is faced with the problem that their real impact only becomes apparent when implemented in the market. Thus, the results should neither be deemed exhaustive nor exclusive. Instead, they serve as a reasonable indication of the impact of robotaxis and the industry's potential future.

Apart from that, the impact of robotaxis was determined solely for the high potential use case. However, since robotaxis are universally applicable, it is likely that impact goes beyond the research findings. In addition, it should be noted that the evaluation was based on a non-exhaustive number of use cases, which leaves room for further analysis.

In addition, the results might not explicitly depict the general social perception of robotaxis, as most survey participants are students or young professionals. As younger people are generally more open to autonomous driving (Winkeler et al., 2019), the survey results may be biased.

Moreover, data was often extracted from federal offices of Germany to serve as a proxy for the European market. Thus, the results should be viewed critically as they could be misleading for European countries with different infrastructure conditions. Additionally, calculations for the value of time and the monetary costs are only comparable if adjusted for PPP. Hence, the results cannot necessarily be transferred to other geographical areas and require further examination.

Lastly, the thesis excludes the effects of the Covid-19 outbreak. However, as the pandemic occurred within the timeframe of the underlying work, it should be noted that this may have led to biases in the primary data.

Nevertheless, the results presented can serve as a basis for further research purposes in the field of robotaxis. Possible research areas could include potential alternative business models, vehicle concepts, penetration rates or effects on vehicle sales.

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Appendices

Appendix A: Levels of driving automation

SAE J3016 six step taxonomy of automation

	SAE Level	Name	Narrative Definition
Driver support feature	Level 0	No Automation	These features are limited to providing warnings and momentary assistance.
	Level 1	Driver Assistance	These features provide steering OR brake/acceleration support to the driver.
	Level 2	Partial Automation	These features provide steering AND brake/acceleration support to the driver.
Automated driving features	Level 3	Conditional Automation	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met. When the feature requests the driver must take over the driving task.
	Level 4	High Automation	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met.
	Level 5	Full Automation	This feature can drive the vehicle under all conditions.

Source: SAE International (2020)

Appendix B: Evaluation of use cases

Note: Appendix 2 displays a detailed evaluation of use cases based on the evaluation criteria of the market potential and ease of implementation. In this part the three assessment criteria of the market potential into account, the size of the use case, the added value of robotaxis and the consumer acceptance. While the size of the use cases was calculated with use cases specific criteria, the added value of robotaxis was evaluated by interview experts and consumer readiness by the questionnaire-based consumer survey.

Assessment of use cases market potential and ease of implementation

	MARKET POTENTIAL				EASE OF IMPLEMENTATION				
Use Case*	**Size (30%)**	**Value added (30%)**	**Consumer acceptance (40%)**	**Ø**	**Technological requirements (25%)**	**Degree of Investment (25%)**	**Speed of adoption (25%)**	**Degree of regulation (25%)**	**Ø**
Work-related commuting	5	4.86	3.35	4.3	3	2	3	2	2.5
Recreational trips (e.g. restaurant visits, etc.)	5	3.43	3.76	4.0	3	2	3	2	2.5
Transportation to airport or train station	2	4.14	4.34	3.6	4	3	4	3	3.5
Rides for business purposes (e.g. meetings, workshops etc.)	3	3.57	3.77	3.5	3	2	3	2	2.5
Accessibility to city centers	2	4.14	3.91	3.4	4	3	4	3	3.5
Shopping, personal or family errands	5	2.71	2.99	3.5	3	2	3	2	2.5
Family rides (e.g. bringing kids to school)	3	4.57	2.74	3.4	3	2	3	2	2.5
Work-related long-distance trips (e.g. by sales representatives)	2	3.71	3.17	3.0	5	4	5	3	4.25
Weekend or day trips to nearby cities	2	2.29	2.72	2.4	4	3	4	3	3.5
Shared long-distance trip	1	2.86	2.50	2.2	5	4	5	3	4.25
Vacation trips	1	2.29	2.49	2.0	5	4	5	3	4.25

*not exhaustive

Assessment criteria for market potential

1. Size of the use case

Use case*	Size	Use case specific assessment criteria
Work-related commuting	**5**	Number of average working days (excl. holidays), Number of commuters, Number of trips per day (Destatis, 2017)
Recreational trips (e.g. restaurant visits, etc.)	**5**	Number of trips for leisure activities (BMVI, 2019), Interview A
Transportation to airport or train station	**2**	Number of people travelling to the airport by car each year (ADV, 2018)
Rides for business purposes (e.g. meetings, workshops etc.)	**3**	Interview D
Accessibility to city centers	**2**	Interview A, Interview B
Shopping, personal or family errands	**5**	Amount of shopping trips per year, number of households, share of people using mode of transportation when shopping (BMVI, 2019)
Family rides (e.g. bringing kids to school)	**3**	Number of school days, number of school kids (Destatis, 2017)
Work-related long-distance trips (e.g. by sales representatives)	**2**	Interview D
Weekend or day trips to nearby cities	**2**	Amount of weekend and day trips, share of vehicle users (Statista, 2011)
Shared long-distance trip	**1**	Amount of people who travel with carpooling per year (BlaBlacar) (Farajallah et al., 2019)
Vacation trips	**1**	Number of holidays lasting five days or more, Share of people using a car (DRV, 2019)

*not exhaustive

Five-point scale for number of rides

Five-point scale	Number of rides in million
5	500 <
4	300 to 500
3	100 to 300
2	50 to 100
1	1 to 50

2. Use cases assessment of interview partners for the added value of robotaxis

	Interview							
Use case*	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**Ø**
Work-related commuting	5	5	4	5	5	5	5	**4.86**
Family rides (e.g. bringing kids to school)	4	5	4	5	5	4	5	**4.57**
Transportation to airport or train station	4	4	3	5	4	5	4	**4.14**
Accessibility to city centers	3	5	5	5	3	5	3	**4.14**
Work-related long-distance trips (e.g. by sales representatives)	3	5	3	5	4	2	4	**3.71**
Rides for business purposes (e.g. meetings, workshops etc.)	3	3	3	4	4	4	4	**3.57**
Recreational trips (e.g. restaurant visits, etc.)	4	3	3	5	2	5	2	**3.43**
Shared long-distance trip	3	4	1	3	4	1	4	**2.86**
Shopping, personal, or family errands	4	3	1	2	3	3	3	**2.71**
Vacation trips	1	4	2	3	3	1	2	**2.29**
Weekend or day trips to nearby cities	1	4	2	3	2	2	2	**2.29**

*not exhaustive

3. Assessment of consumer acceptance based on survey responses

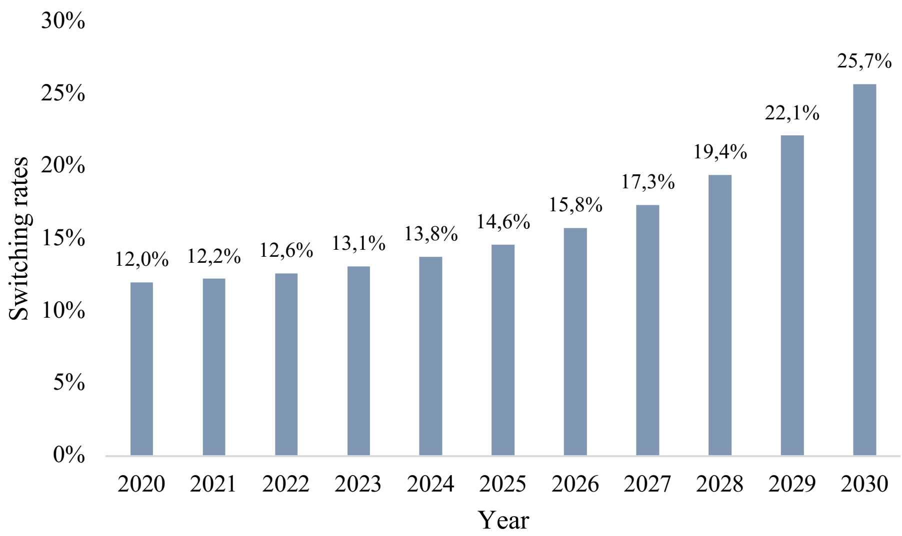
	Number of responses from consumer survey					
Use case*	**5**	**4**	**3**	**2**	**1**	**∅**
Transportation to airport or train station	43	30	12	1	0	**4.34**
Accessibility to city centers	26	37	12	8	2	**3.91**
Rides for business purposes (e.g. meetings, workshops etc.)	23	33	19	9	2	**3.77**
Recreational trips (e.g. restaurant visits, gym, etc.)	28	24	23	7	4	**3.76**
Work or education related commuting	17	28	18	14	9	**3.35**
Work-related long-distance trips (e.g. by sales representatives)	14	27	20	10	15	**3.17**
Shopping, personal or family errands	7	24	23	23	7	**3.01**
Family rides (e.g. bringing kids to school)	7	16	20	34	9	**2.99**
Weekend or day trips to nearby cities	10	15	22	19	20	**2.74**
Shared long-distance trip	11	10	19	17	29	**2.72**
Vacation trips	9	10	20	22	25	**2.50**

*not exhaustive

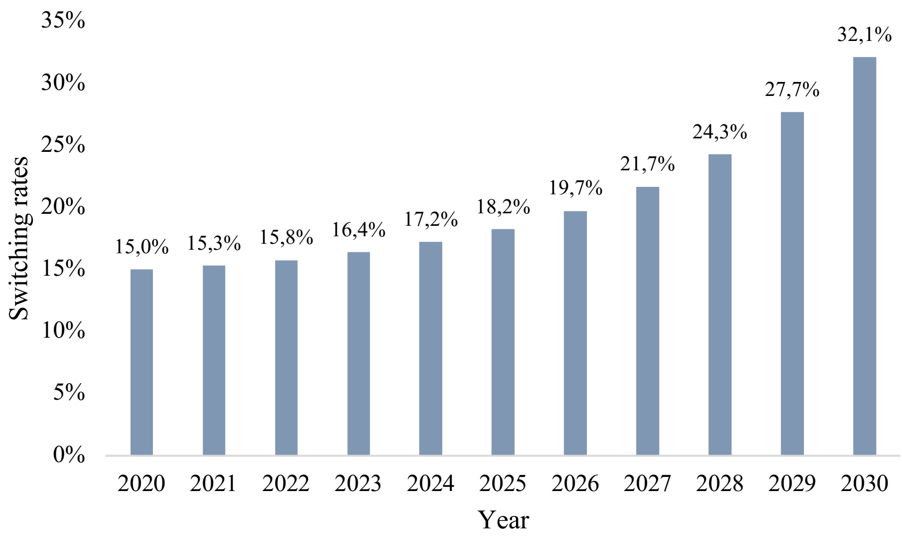
Appendix C: Switching rates for shift in consumer preferences

Note: Appendix C illustrates the switching rates towards robotaxis for private car and public transportation commuters. The two figures display a forecast of a percentual shift in consumer preferences towards robotaxis. In the first table it can be seen that in 2030 every fourth private car commuter would be willing to commute by robotaxis. In the second table it is displayed that in 2030 even every third public transportation user would be willing to commute by robotaxi.

Potential shift in consumer preferences towards robotaxis for private car commuters



Potential shift in consumer preferences for public transport commuters



Appendix D: Interview summary

Note: Appendix D provides interview summaries for 7 conducted semi-structured expert interviews. The interviews were mainly held in German and are translated into English. Each interview summary contains a list of main topics and corresponding responses in form of citations from the interview participants. The industry experts had significant expertise in the field of autonomous driving and had at least 2 years of industry affiliation. An overview of interview participants including their profession, expertise, and company description is given in Chapter 3.

Interview A – Duration 30 minutes	
Topic	**Response**
Financial costs	*"To be adopted, robotaxis need to be affordable for the general public."*
Modal shift	*"We will have a decline in traditional car ownership, and it is going to increase the adoption of robotaxis and electric vehicles."* "*The benefits of robotaxis such as time efficiency, cost savings, and safety, reinforce the trend towards mobility-as-a-service. There is no reason for owning a vehicle or rely on public transportation when robotaxis exist.*" *"Some people will still like the physical aspect of driving a car."*
Speed of adoption	*"The implementation for early roll outs and small vehicle fleets will take around 10 years, while penetration rates above 50% are going to take around 20 years"* *"The speed of adoption depends on four factors: user costs, technology, regulation and monetization."* *"There is a solid progression on bringing costs down to commercialize robotaxis. And it seems like there is some path forward on the regulation."* *"Technology needs to be ready for Level 4 and 5 autonomous driving. However, even when the technology exists, we are relying on governments and municipalities to approve the technology."* *"How to monetize the concept of robotaxis is yet uncertain."*
Competitive landscape	*"The industry becomes a highly competitive environment."* *"In the-long term there will be many setbacks and unexpected bankruptcies for some companies in the industry, partly due to robotaxis."*

	"With autonomous technology, there will be a lot of new entrants and partnerships in the automotive industry." *"OEMs potentially get cut out of the end user revenue because there might be some other players that provide a robotaxi service that are better at software development."* *"Although electric vehicle technology is the foundation for autonomous vehicles, OEMs are not investing enough. There will be no autonomous vehicles with a combustion engine."*
Operating environment	*"A role out will happen mainly in urban centers, as the concept of autonomous taxis requires a comprehensive infrastructure and sufficient consumer demand to be adopted."*
Business models	*"No one knows how robotaxis are going to be monetized. Ultimately, nobody knows how robotaxis are going to impact our industry."* *"Regardless of the business model the consumer is the most important factor when it comes to the adoption of robotaxis."*
Use cases	*"Robotaxis can be used almost holistically for typical urban transportation."* *"There is a high need for short trips for example trips to the grocery store."* *"Family use cases are a big topic; however, they require a lot of consumer trust. As a parent you want to make sure your kid is safe when you put them in a car without a driver."* *"You are going to see last mile delivery."* *"The use cases where implementation is going to be difficult are use cases with longer trip range. This is because robotaxis rely on electric vehicle technology."*

Interview B – Duration 60 minutes	
Topic	**Response**
Financial costs	*"Today, the driver's fee represents the largest part of the total fee paid by shared mobility users. Therefore, with omitting the driving task, robotaxis will be very cheap for consumers."* *"With a medium penetration rate, it is possible to achieve prices similar to those for public transportation."*
Modal shift	*"The robotaxi replaces not only public transportation but also taxis and private cars. However, there will always be a portion of public transport and car users"*

	"There will be a change from ownership to mobility-as-a-service since private vehicles are not so much a status symbol anymore and are becoming more expensive with autonomous technology." *"Private vehicle and public transportation are becoming increasingly unattractive as they no longer have an advantage over robotaxis. The benefit of robotaxis is that they are always available at any time."* *"Consumers don't want to own a vehicle in the future, because there is always a vehicle available with a robotaxi."*
Speed of adoption	*"In European cities where traffic is very multimodal, autonomous driving is adapted rather slowly."* *"Regulations will slow down the implementation of robotaxis."*
Difference between European and US market	*"The USA has an advantage as a technology location due to its approval principle. On the other hand, in Germany, everything that comes onto the road must be certified by TUV, which must issue an approval. Therefore, German OEMs are already testing in the USA."* *"There are also differences in the history of the companies. A start up like Tesla can take setbacks but for a German OEM that stands for safety, quality and efficiency, a single accident can lead to a scandal."* *"European OEMs rather choose a conservative evolutionary approach, while Tesla makes it very dynamic evolutionary and Waymo makes it revolutionary."*
Competitive landscape	*"There will be many more stakeholders in the future."* *"Every OEM is afraid of becoming only a supplier for tech companies such as Amazon, Google, Apple and so on."* *"Collaborations of industry players will reduce individual investment costs."*
Operating environment	*"Intercity use cases are the easiest to implement but will not add value to the current transportation system."* *"Inner city use cases will be implemented last, after suburban and Intercity use cases."* *"From a technological and economical perspective, robotaxis are likely to be adopted last in rural areas, as there are many edge cases and the demand will be not sufficient."* *"The number of edge cases in an operating environment indicate whether robotaxis are easy to implement or not. A high number of edge cases requires sufficient technological development."*

Infra-structure	*"As soon as a critical mass switches to robotaxis, more and more people get on the road, which will initially lead to a traffic collapse."* *"There will be a lot of parking spaces which lead to a widening of the traffic area."*
Business models	*"The consumers are no longer a one-dimensional aspect but has to be considered in three dimensions, owner, user and operator. As a result, business models are becoming more customer-oriented, but how OEMs will fit into this changing business model is something they themselves do not know yet."*
Use cases	*"When considering use cases, the mobility needs of persons should be considered first. People are very skeptical about autonomous driving as most people cannot imagine, so it is important to see what mobility needs must be fulfilled."* *"In order to determine the impact of robotaxis and to define the relevant use cases, the approach is rather to try to satisfy the mobility need of the consumer."* *"Mobility needs remain the same over time."* *"The opportunity costs of the consumer differ depending on its mobility need."* *"Vehicle concepts play a significant role to satisfy the mobility needs of the consumer."* *"If you look from the use case side it is important to compare robotaxis with other means of transportation to see if they can add value to the transportation system"*

Interview Protocol C – Duration 60 minutes	
Topic	**Response**
Financial costs	*"Compared to a private car it will be easier and cheaper to drive robotaxis."*
Modal shift	*"Robotaxis will equalize public transportation."* *"Robotaxis can replace a whole piece of public transportation."*
Speed of adoption	*"It will certainly take another 10 years for the technology to become applicable and another 10 years for it to become established - by 2040 we could have a broad application."* *"Government and cities play a very important role in the speed of adoption of robotaxis. Whether the technology is ready for the market or not depends on the government's approval."*

Competitive landscape	*"Established car manufacturers, do not want to be the first on the market, they rather try to make autonomous cars as safe and reliable as possible."* *"While established technology companies like Google (Waymo) tend to follow a revolutionary development, European OEMs tend to follow an evolutionary path and gradually implement autonomous features in the cars."* *"Technology companies have the financial resources to follow a revolutionary development of autonomous technology."* *"As an OEM, it is particularly important to create partnerships with companies that already have an customer interface."* *"The competition in the industry is high since the market is limited to various cities."* *"The providers of robotaxis will differ from city to city because every urban center has unique requirements."*
Infra-structure	*"In the beginning there will be massive losses in terms of traffic flow, because the cities become more and more congested and there are no synergies between exiting transportation means and robotaxis."*
Business models	*"It is possible that Waymo may sell or rent the software."* *"Companies will shape the business model according to consumer preferences."*
Use cases	*"The relevance of use cases depends on the target group of the respective robotaxi provider. An elite car manufacturer, for example, does not take children as a target group."* *"Intercity use cases will be the first to be implemented, since the robotaxi primarily drives on the highway."*
Implement-tation	*"The road infrastructure and the diversity of road users depend on whether a use case is easy to implement."*
Technology	*"About 3 years ago, autonomous driving was a hot topic. Nowadays, unfortunately, the interest has decreased."* *"The technology roadmap is extremely difficult to predict as there are extreme global cross-country differences"* *"The technological status of the current industry is still in its infancy and not very far advanced."*

Challenges	*"It is important to be crisis-proof and adaptable to withstand external shocks."* *"Ethical barriers and other questions still need to be clarified to establish autonomous driving nationwide."* *"For many in the industry it is difficult to spend money on a market that does not exist yet."* *"No company wants to invest a lot of money in autonomous technology if there is no social acceptance. On the other hand, social acceptance only comes with implementing expensive autonomous features into the cars."*

Interview Protocol D – Duration 60 minutes	
Topic	**Response**
Financial costs	*"A robocar is initially too expensive to own due to the technology involved. However, there will be a price degression so that in future households will be able to afford such vehicles."* *"Pricing of robotaxis will be more expensive, but still competitive with public transportation. Whether a consumer then decides to use a robotaxi depends on its price elasticity."* *"The price for a robotaxi will be dependent on various factors such as the vehicle type, the interior, the business model and so on."*
Modal shift	*"If there are robotaxis, public transportation will suffer."* *"Robotaxis are time efficient since the people can engage in other activities during the ride."* *"To prevent public transportation from being fully replaced, cities will try to regulate the market because they are the owners of the network."* *"It is expected that, a dramatic modal shift will occur when robotaxis achieve significant rates of adoption and consumers gain trust in the technology. To what extent remains to be seen."*
Value of time	*"One of the main effects of Robocars is that they are 24/7 active and available at any point in time."* *"Autonomous vehicles provide maximum utilization and thus productive time."* *"Robotaxis show you how long it takes to get from A to B. This time transparency is a big advantage."*
Speed of adoption	*"People with higher incomes can afford robotaxis and are among the early adopters"* *"The main problem with rapid implementation is regulation and consumer trust in technology".*

	"Every country in Europe has different requirements and demands certification for autonomous technology. What is certified in Germany does not mean that certification will also take place in the Netherlands." *"There will be markets that implement robotaxis easily. In China, for example, the implementation will probably be very fast because the market is less regulated."* *"The development and adoption of robotaxis can be illustrated by a product lifecycle, a S-shaped curve. We are currently at the beginning of the curve."* *"In 2040 at the earliest, robotaxis will be ready for area-wide deployment."*
New sources of Income	*"For autonomous driving, OEMs assume a five main sources of income. These consists of hardware, software, fleet management, data management and service (content)."* *"The hardware will most likely be provided by OEMs, while the software will be in the hands of technology companies or start-ups."* *"Data management could help OEMs to lift up their vehicle sales and after-sales business."* *"OEMs do not have a chance to control the digital customer interface since there are already established players such as Uber or Waymo in the market. Therefore, there will be various collaborations in the industry."* *"Ride-hailing companies have digitalized the customer interface."* *"A collaboration model can also be expected for fleet management and service."* "*OEMs will collaborate with entertainment providers such as Netflix and charge a premium for allowing them to offer its services in their car*."
Business models	*"Not everything will be an on-demand or sharing market there will still be households who will own cars"* *"By owning a vehicle, private households have the possibility of P2P sharing. In this way, the vehicle can be refinanced, or the household can earn some extra money."* *"Future business models will include platforms that tell you which mode of transportation is currently best suited to get from A to B the fastest."* *"Subscription models for robotaxis are very likely."*
Use cases	*"Saving time is the most important thing for people."* *"All long-distance use cases have high business relevance for premium providers."* *"The market potential of a use case is critical for the implementation of robotaxis. Without market potential there is no implementation."* *"For short-distance use cases, the price ultimately counts, unless the use cases are related to business and work".*

	"Due to the time savings and thus high opportunity costs, work related use cases are of great importance for robotaxis." *"All use cases for robotaxis that lead to high time savings are of great relevance for the consumer and therefore the industry".*
Technology	*"For rapid adoption, robotaxis require area-wide 5G extension."*
Challenges	*"It is a huge challenge to recognize how the future of the industry will look like. This is partly done by making best guesses and empirically sound predictions"*

Interview Protocol E – Duration 40 minutes	
Topic	**Response**
Financial costs	*"Initially, the use of robotaxis will not be economical. However, cross-subsidization contributes to economic use."* *"Often a stakeholder group apart from the traveler may pay for the rides of a passenger, for example the passengers employer, the gym, the restaurant etc.. The relevant question in this context is: Will tomorrow the person who uses it still pay for mobility or will the person who benefits from it pay?"*
Modal shift	*"Robotaxis leads to a restructuring of ownership structures."* *"Ownership and use of public transportation will decline."* *"Initially, robotaxis will cause a traffic collapse. Studies confirm this with regard to Uber and Lyft, a 15% increase in traffic in the cities resulted."*
Speed of adoption	*"Infrastructure must be adapted for a rapid implementation of autonomous driving."* *"There is great uncertainty about the timing of technical feasibility."*
Competitive landscape	*"Ride-hailing companies can leverage their existing user base to operate robotaxis. They might be among the early adopters as the elimination of the driver will cut out the greatest cost component."*
New sources of Income	*"OEMs are already trying to position themselves as service providers. With robotaxis they will offer a greater range of service."* *"Fleet management is a crucial part for the operation of robotaxis."* *"Cooperation's with fleet operators and other companies are expected to generate new revenue streams."* *"OEM have a great expertise in hardware development and will continue to be the predominant players in the market."*

	"*OEMs will focus less on operations and more on the reuse of consumer data and the targeted placement of content in the vehicle*"
Operating environment	*"Inner city traffic is the most challenging thing for robotaxi technology."* *"Motorways are among the first fully automated operating environments. Long distance business trips and commuting are therefore technically feasible first.*"
Infra-structure	*"It has long been considered that infrastructure should not be changed, since in Europe city centers are often historic."* *"Today it is considered that the infrastructure must be able to take over the steering of vehicles in order to technologically support vehicles and make them safer. This is particularly useful for complex traffic situations."* *"The European infrastructure needs a widespread extension of 5G."*
Use cases	*"From an economic point of view a distinction between private use cases and business use cases is necessary as they differ in their opportunity costs."* *"Whether a use case is applicable depends on how large its share of the traffic volume is."* *"Commuting makes up a very large part of traffic as it also takes place at defined times. The peak traffic conditions can be improved by robotaxis."* *"All urban use cases are very relevant."*

Interview Protocol F – Duration 40 minutes	
Topic	**Response**
Consumer	*"Consumer acceptance and demand will ultimately determine whether robotaxi will prevail or not."*
Modal shift	*"At some point, robotaxis will significantly contribute to road safety."* *"Safety is the most important factor for the use of the new technology - both as individual transport and in sharing concepts."*
Speed of adoption	*"For the adoption there must be a uniform legal basis at UN and EU level."* *"Consumer trust and acceptance is crucial for the adoption of robotaxis."* *"From a technical point of view, implementation of robotaxis will be rather fast. In which environments these vehicles can be used is another question. Municipalities play a major role and may introduce special lanes, to make the use of a robotaxi more attractive."*
Infra-structure	*"Especially in suburban areas, cities often cannot fulfil their obligations to provide sufficient mobility to their inhabitants."*

Competitive landscape	*"OEMs will be able to build vehicles even more economically in the future and combine them with the IT know-how of smaller IT companies. Often these are already part of a large OEM, as car manufacturers acquire these skills."* *"OEMs will continue to be entitled to use their expertise in vehicle development, if they also manage to build up AV competence - through cooperation or takeovers - and shorten their classic product cycles."*
Use cases	*"In the private sector, robotaxis will initially occur mainly in the urban area on fixed routes."* *"For the private use, robotaxis will be initially used for routes that have certain routines: daily commutes to work or even children's trips to school or leisure activities."* *"The most frequently discussed use cases in the industry are work-related commuting, or urban use cases that can be covered by public transportation. They are the most likely to be economically relevant."* *"AV in the field of transport and logistics will be established much faster.* *"A use cases business relevance and sufficient trust in technology are relevant to implement robotaxis."*
Ease of Implemen-tation	*"Short distances in a restricted area are easy to implement, for example commuting on an exhibition site."* *"Any route that does not require human-controlled individual traffic and has no other topographic challenges is suitable for robotaxis"* *"It becomes difficult for the robotaxi when there is a deviation from normal road traffic, for example, in inner-city areas, when cars are parked incorrectly, or roads are temporarily closed."*
Challenges	*"Today, robotaxis have high investment costs, high regulatory demand and insufficient consumer acceptance."*

Interview Protocol G – Duration 30 minutes	
Topic	**Response**
Benefits of AVs	*"Robotaxis will complement existing transportation options and add value in urban and suburban areas since they have the potential to optimize traffic."* *"Autonomous vehicles represent a better mobility solution for cities."* *"The advantage is direct on-demand travel from point A to point B. You don't have to change trains twice to reach your destination as you possibly have to with public transportation."*

Speed of adoption	*"Between 2025-2030 there will be a scenario where inner-city areas will be opened up to autonomous vehicles. Only then will it become clear whether the implementation is worthwhile."*
Implemen-tation	*"For introducing robotaxis the consumer must first be convinced by digital experiences and get an understanding of autonomous driving."* *"Cities play a major role in the implementation of robotaxis. In the Netherlands, for example, city centers are to be restricted to individual traffic. Cities must offer an alternative. Therefore, it may be that autonomous driving covers the last mile to the city center."* *"Regulation of private transport must take place to support the introduction of autonomous vehicles."* *"To be adopted, robotaxis require more pilot projects to enhance the technological development."*
Competition	*"There will be major collaborations in the industry."* *"With regard to Artificial Intelligence (AI), global car manufacturers are already working together."* *"Premium manufacturers will probably focus on selling autonomous luxury cars while OEMs in the lower- and middle-class segment offer a low-cost shuttle or taxi solution."*
Business models	*"Business models will change towards services rather than sales."* *"Providing a service in rural areas is not a financially viable business model because the costs are too high, and demand and use will be very low."*
Infra-structure	*"With robotaxis the infrastructure for parking is no longer required and the space can be used differently."*
Use cases	*"Robotaxis can be used for commuting to work or even taking children to school. However, they should cover several use cases at once and will be used universally."* *"All mobility needs of the consumer must be met."*
Challenges	*"It will not be possible to switch to autonomous driving at once. There will still be conventional cars on the roads."* *"The biggest technological challenge is mixed traffic."* *"The safety aspect is not yet in place and can only be improved through pilot projects."*

Appendix E: Consumer survey results

Note: Appendix E illustrates the results of the questionnaire-based consumer survey. The survey included in total 102 observations from which 16 observations with missing data were excluded. This part presents the sample and displays the questions and responses of the survey.

Sample overview

		Responses	Percentage
Respondents	Number	86	100%
Gender	Male	45	52.4%
	Female	40	46.4%
	Prefer not to answer	1	1.2%
Age	under 18	1	1.2%
	18 - 24 years	29	33.3%
	25 - 34 years	51	59.5%
	35 - 44 years	2	2.4%
	45 - 56 years	-	-
	55 - 64 years	2	2.4%
	65 and older	1	1.2%
Nationality	German	63	73.3%
	Portuguese	8	9.3%
	USA	5	5.8%
	Netherlands	4	4.7%
	Other	6	6.9%
Occupation	Student	50	58.1%
	Employed	30	34.9%
	Self-employed	4	4.7%
	Unemployed	2	2.3%
	Retired	-	-
	Other	-	-
Residential Area	Urban	65	75.6%
	Suburban	20	23.2%
	Rural	1	1.2%
Car Ownership	Yes	47	54.7%
	No	39	45.3%
Income	Less than €1,000	26	30.2%
	€1,000 to €1,999	17	19.8%
	€2,000 to €3,999	18	20.1%
	€4,000 to €5,999	12	14%
	€6,000 to €7,999	3	3.5%
	€8,000 to €9,999	-	-
	€10,000 to €15,000	-	-
	More than €15,000	1	1.2%
	Prefer not to answer	9	10.5%

Survey results

Question	Response options	Responses	Percentage
1) How often do you use public transportation?	Daily	20	23.26%
	4 to 6 times a week	15	17.44%
	2 to 4 times a week	10	11.63%
	Once a week	11	12.79%
	Less than once a week	20	23.26%
	Never	10	11.63%
2) How often do you use a private car?	Daily	21	24.42%
	4 to 6 times a week	15	17.44%
	2 to 4 times a week	16	18.60%
	Once a week	5	5.81%
	Less than once a week	18	20.93%
	Never	11	12.79%
3) How often do you use on demand services such as a taxi or an Uber?	Daily	3	3.49%
	4 to 6 times a week	3	3.49%
	2 to 4 times a week	12	13.95%
	Once a week	13	15.12%
	Less than once a week	42	48.84%
	Never	13	15.12%
4) How often do you use a bike, scooter or other means of transportation (skateboard, inline skates, etc.)?	Daily	6	6.98%
	4 to 6 times a week	10	11.63%
	2 to 4 times a week	10	11.63%
	Once a week	12	13.95%
	Less than once a week	28	32.56%
	Never	20	23.26%

5) What are the most important factors for you when choosing between different means of transportation? Please rank the following factors.							
Factor	**Rank**						**Mean**
	1	**2**	**3**	**4**	**5**	**6**	
Time efficiency	30	30	18	5	3	0	**2.08**
Flexibility (no fixed schedules)	15	23	16	13	10	9	**3.08**
Convenience	18	9	22	21	14	2	**3.12**
Price	11	14	14	16	15	16	**3.67**
Safety	10	10	9	17	24	16	**3.97**
Environmentally friendly	2	0	7	14	20	43	**5.08**

6) Imagine that there were robotaxis as an alternative to the current means of transportation. Would you be interested in using a robotaxi? Please indicate your level of interest.		
Interest in using a robotaxi	**Mean on a scale from 1 to 10**	**Percentage**
	6.56	65.5%

Questions	**Response options**	**Responses**	**Percentage**
7) Since most of the traffic accidents are caused by human error, I believe robotaxis are capable of making a significant contribution to road safety.	Strongly agree	13	44.19 %
	Somewhat agree	36	40.70 %
	Neither agree nor disagree	20	11.63 %
	Somewhat disagree	14	2.33 %
	Strongly disagree	3	1.16 %
8) I believe robotaxis to be time efficient and comfortable.	Strongly agree	21	24.42%
	Somewhat agree	47	54.65%
	Neither agree nor disagree	14	11.63%
	Somewhat disagree	3	6.98%
	Strongly disagree	1	4.65%
9) It would be convenient for me to order a robotaxi which picks me up and drops me off at my desired location.	Strongly agree	38	44.19%
	Somewhat agree	35	40.70%
	Neither agree nor disagree	10	11.63%
	Somewhat disagree	2	2.33%
	Strongly disagree	1	1.16%
10) Since the driving task is omitted, it is a great advantage for me that I can spend my time with other	Strongly agree	32	37.21%
	Somewhat agree	34	39.53%
	Neither agree nor disagree	10	11.63%

things like work or entertainment on board.	Somewhat disagree	6	6.98%
	Strongly disagree	4	4.65%
11) If robotaxis turn out to be cheaper than ride-hailing services such as Uber or Lyft, I believe I will consider them an attractive mobility option.	Strongly agree	51	59.30%
	Somewhat agree	24	27.91%
	Neither agree nor disagree	5	5.81%
	Somewhat disagree	5	5.81%
	Strongly disagree	1	1.16%

12) Please indicate for each situation your willingness to use a robotaxi compared to other modes of transportation (public transportation, private vehicle, walking, ride-hailing, etc.).

Example:

I would (1) never use a robotaxi for daily family rides (e.g. bringing the kids to school).

I would (5) most of the time, use a robotaxi for daily family rides (e.g. bringing the kids to school).

Use case	Response options	Responses	Percentage
1) Family rides (e.g. bringing kids to school) - The robotaxi would pick up your kids and drop them off at school	Most of the time	7	8.14 %
	Frequently	16	18.60 %
	Sometimes	20	23.26 %
	Rarely	34	39.53 %
	Never	9	10.47 %
2) Shopping, personal, or family errands (e.g. grocery shopping)	Most of the time	7	8.14 %
	Frequently	24	27.91 %
	Sometimes	23	26.74 %
	Rarely	25	29.07 %
	Never	7	8.14 %
3) Recreational trips (e.g. restaurant visits etc.)	Most of the time	28	32.56 %
	Frequently	24	27.91 %
	Sometimes	23	26.74 %
	Rarely	7	8.14 %
	Never	4	4.65 %
4) Work - related commuting	Most of the time	17	19.77 %
	Frequently	28	32.56 %
	Sometimes	18	20.93 %
	Rarely	14	16.28 %
	Never	9	10.47 %
	Most of the time	10	11.63 %

5) Weekend or day trips to nearby cities	Frequently	15	17.44 %
	Sometimes	22	25.58 %
	Rarely	19	22.09 %
	Never	20	23.26 %
6) Vacation trips	Most of the time	9	10.47 %
	Frequently	10	11.63 %
	Sometimes	20	23.26 %
	Rarely	22	25.58 %
	Never	25	29.07 %
7) Work-related long-distance trips (e.g. by sales representatives)	Most of the time	14	16.28 %
	Frequently	27	31.40 %
	Sometimes	20	23.26 %
	Rarely	10	11.63 %
	Never	15	17.44 %
8) Rides for business purposes (e.g. meetings, workshops etc.)	Most of the time	23	26.74 %
	Frequently	33	38.37 %
	Sometimes	19	22.09 %
	Rarely	9	10.47 %
	Never	2	2.33 %
9) Transportation to airport or train station	Most of the time	43	50 %
	Frequently	30	34.88 %
	Sometimes	12	13.95 %
	Rarely	1	1.16 %
	Never	-	-
10) Accessibility to city centers	Most of the time	26	30.59 %
	Frequently	37	43.53 %
	Sometimes	12	14.12 %
	Rarely	8	9.41 %
	Never	2	2.35 %
11) Shared long-distance trip	Most of the time	11	12.79 %
	Frequently	10	11.63 %
	Sometimes	19	22.09 %
	Rarely	17	19.77 %
	Never	29	33.72 %