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Sustainable Mobility in Rural Areas based on Autonomous Vehicles and Mobility On-Demand

A Pre-feasibility Study for Lower Austria

A Master's Thesis submitted for the degree of
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Affidavit

I, **LAURA BEITZ**, hereby declare

1. that I am the sole author of the present Master's Thesis, "SUSTAINABLE MOBILITY IN RURAL AREAS BASED ON AUTONOMOUS VEHICLES AND MOBILITY ON-DEMAND. A PRE-FEASIBILITY STUDY FOR LOWER AUSTRIA", 90 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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Abstract

In the past century, private automobiles have shaped personal mobility by enabling fast and convenient point-to-point travel. However, this development is having a serious effect on the sustainable nature of our transport system. To transform personal transportation to a sustainable mobility system, two fields of research are currently receiving considerable attention: autonomous vehicles and mobility on-demand.

So far, the focus of this research has been on implementing autonomous vehicles and mobility on-demand in urban environments, with far too little attention paid to rural areas. Thus, the purpose of this thesis is to evaluate the potential of autonomous vehicles applied in a mobility on-demand concept in Lower Austria, in order to provide sustainable mobility in rural areas. In the course of this, a new mobility model derived from the two concepts is developed. The model is based on a literature review as well as a quantitative analysis of secondary data.

The findings confirm the hypothesis that an autonomous mobility on-demand model can increase mobility and make personal transportation more sustainable in Lower Austria. One of the more significant findings to emerge from this study is that autonomous vehicles can eliminate the limitations of current mobility on-demand models and allow them to expand to rural areas. It was also shown that the developed model would have a substantial impact on Lower Austria, enable the use of transport resources more efficiently and ultimately change the way we perceive automobile travel. Taken together, these results suggest that further research is necessary to evaluate the feasibility of the developed model. This research should be undertaken now to ensure that Lower Austria is ready when autonomous vehicles hit the roads. Furthermore, the study has gone some way towards enhancing our understanding of autonomous vehicles and their ability to improve personal transportation in rural areas.

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Abbreviations

ACC	Adaptive Cruise Control
ADAS	advanced driver assistance systems
AMOD	Autonomous mobility on-demand
BMVI	Ministry of Transport and Digital Infrastructure
BMVIT	Austrian Ministry for Transport, Innovation and Technology
CACC	cooperative adaptive cruise control
CCAV	Centre for Connected and Autonomous Vehicles
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2 eq.	Carbon dioxide equivalent
DARPA	Defence Advanced Research Projects Agency
DMV	Department of Motor Vehicles of Nevada
DOT	US Department of Transportation
DOT	Department of Transportation
ECMT	European Council of Ministers of Transport
EPRS	European Parliamentary Research Service
EU	European Union
EUR	Euros
GBP	Great British Pound
GHG	Greenhouse Gase
HC	Hydrocarbon
ITS	intelligent transport system
km	kilometres
km/h	kilometres per hour
LKA	Lane Keeping Assist Systems
LTA	Land Transport Authority of Singapore
MIT	Massachusetts Institute of Technology
Mt	million tonnes
NH_3	Ammonia
NHTSA	National Highway Traffic Safety Administration
NMVOC	Non-methane volatile organic compounds
NO_x	Nitrogen oxides
PA	Park Assist
PRT	Personal Rapid Transport
SAE	International Society of Automotive Engineers
SAVI	Singapore Autonomous Vehicles Initiative
SMART	Singapore-MIT Alliance for Research and Technology
SO_2	Sulphur dioxide
TNC	Transportation Network Companies
UK	United Kingdom
US	United States
USD	United States Dollars
V2I	vehicle to infrastructure
V2V	vehicle to vehicle
V2X	vehicle to other devices
VKT	Vehicle Kilometres Travelled
WHO	World Health Organisation

1. Introduction

Fighting climate change and reducing greenhouse gas (GHG) emissions are one of the biggest challenges we are facing in this century. In order to meet this challenge, the European Union (EU) has set itself the ambitious target to reduce its GHG emissions by 80 % below 1990 levels by 2050 (European Commission 2015). This target is part of the EU's 2050 low-carbon economy roadmap. The roadmap provides that by 2050 all EU Member States should have switched to clean technology, low-carbon energy from renewable energy resources and a resource-efficient society.

For the transport sector this means a complete change. Our current transport system is shaped by personal mobility. Private automobiles allow people to travel fast, at any time and with high convenience to their desired destination. However, this freedom of travel also has its price. It has led to the production of GHG emissions such as CO_2, NH_3, NO_x, NMVOC, CO und SO_2, a dependency on oil, congestion and increasing traffic fatalities. In Austria alone, the traffic sector produced 21.7 Mt of CO_2 equivalent in 2012 (Umweltamt 2014). Compared to 1990, this was an increase of 54 % (Umweltamt 2014). The high emissions of CO_2 are due to an on-going increase in traffic in Austria, which is also responsible for the growing problem of congestion. INRIX (2014) found that an Austrian driver spends 24 hours every year stuck in traffic congestion. The increasing traffic demand is also causing increasing costs and road accidents. ASFINAG, Austria's state-owned motorway operator announced that it will invest 470 million EUR in renewing existing motorways and tunnels in 2016 (APA 2016). In 2014, 47,670 people were injured in road accidents and 430 died (BMVIT 2014). The transport sector is also Austria's biggest oil consumer. In 2013, the transport sector consumed 65 % of the country's oil demand (IEA 2014).

The problems caused by personal mobility are even worse on a global scale. Due to the rapid increase in world population and the economic development of developing and developed countries, car ownership is growing sharply (Sperling and Claussen 2002). In 2015, more than 89 million passenger cars were produced (OICA 2014) and the forecasts are that in 2020 light-vehicle car sales will have reached 111 million (Stastica 2016). As a result, private car ownership together with the transport infrastructure that has developed around it is inefficient and unsustainable, as it will increase CO_2 emissions even further. Consequently, the challenge is to find ways to "mitigate the negative effects of transport […] while ensuring positive aspects of mobility" (EEA 2012). Otherwise a successful transition to a low-carbon and sustainable society will not be feasible.

To allow such a successful transition, a lot of research has been conducted. Two emerging trends in this research field are autonomous vehicles and mobility on-demand. Autonomous vehicle, also known as self-driving or driverless vehicle, can be broadly defined as vehicles that drive, steer, accelerate and brake without human intervention (Department for Transport 2015). Instead of humans, computer algorithms take over the driving task, making it more convenient for humans to travel and getting rid of inefficiencies in human driving. Autonomous vehicles are therefore predicted to change the way we perceive and use automotive travel as well as to enable a new area of mobility.

Mobility on-demand has a similar vision. Mobility on-demand can be defined as “the use of shared vehicles accessed on demand” (Greenblatt and Shaheen 2015). Instead of using private vehicles, people can travel in shared vehicles, shared rides or hail a ride via a smartphone app. This allows a more efficient use of shared resources and if the mobility on-demand service is set up well, it can serve as an attractive alternative to car ownership (Greenblatt and Shaheen 2015), (Rayle, et al. 2014).

Both emerging trends have received a lot of attention recently and promise to decrease the negative externalities of our current transportation system making personal mobility more sustainable. At the time of writing, the focus in these two fields of research has been on the implementation and impacts of these concepts on urban transportation (Fournier, et al. 2015), (Ruhrort, et al. 2014) (Firnkorn and Müller 2011), (Alessandrini, et al. 2015). However, little to no attention has been given to rural areas. In my opinion, this is a mistake.

In countries like Austria, where 65 % of people live in rural areas (Statistik Austria 2013), personal mobility is an important issue. A significant number of people that live in rural areas are highly dependent on their cars. Most people need their car to go to work, do their shopping etc. Although trains and buses operate in these areas, it is difficult for the population to decrease their car use and switch to public transport, as public transport is limited in rural areas. For Austria to switch to a low-carbon economy by 2050, it will be key for the country to develop a sustainable mobility concept that includes rural areas and is sensitive to the specific circumstances of the rural population.

The aim of this thesis is to develop a new mobility model based on autonomous vehicles and mobility on-demand for Lower Austria and to evaluate its potential to provide sustainable mobility for rural areas. The focus is therefore on personal mobility and not on freight traffic. The hypothesis of this thesis is that a mobility on-demand model based on autonomous cars can increase mobility and make traffic more sustainable in Lower Austria.

In order to ensure that the developed model is not only low in carbon production, but also well perceived by society and the economy, this thesis uses the concept of sustainable mobility as defined by the European Council of Ministers of Transport (ECMT). The ECMT (2001) defines a transport system as sustainable if it

> *allows the basic access and development needs of individuals, companies and societies to be met safely and in a manner consistent with human and ecosystem health, and promotes equity within and between successive generations; is affordable, operates fairly and efficiently, offers choice of transport mode, and supports a competitive economy, as well as balanced regional development; limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and, uses non-renewable resources at or below the rates of development of renewable substitutes while minimising the impact on the use of land and the generation of noise.*

This definition suggests that a modern transport system should be evaluated on the impacts it has on the society, the economy and the environment. These three pillars will also be the basis of evaluation to assess the sustainable nature of the developed mobility concept.

Given this, the research questions of this thesis are as follows: Does a mobility on-demand model based on autonomous vehicles have the potential to provide a sustainable mobility concept for Lower Austria? What are the economic, environmental and social effects of such a mobility model? How could a mobility model based on autonomous mobility on-demand that services the travel demand of Lower Austrians be designed?

To answer these questions this thesis conducts a literature review as well as a quantitative analysis of secondary data. The results of this thesis indicate that the developed model has the potential to change personal mobility and to mitigate the negative effects personal mobility has on the environment today. Furthermore, the findings suggest that it can increase people's mobility, without creating more privately owned automobiles, leading to a positive impact on society and the economy. To conclude, the findings of this study have a number of important implications for future research.

This thesis is structured as follows. Chapter 1 outlines the theme and motivation of the thesis. Chapter 2 examines the concept and technology behind autonomous vehicles. It discusses the different phases of automation and identifies current efforts made by the private and public sector as well as its potential impacts on the economy, environment and society. Chapter 3 focuses on mobility on-demand as an emerging trend in personal mobility. The research is based on a similar method as applied in chapter 2. Chapter 4 then goes on to analyse the mobility study conducted by Herry Consult GmbH (2012) in order to identify the mobility needs and travel patterns of the population in Lower Austria. The findings of this and the previous chapters are combined and applied in a new mobility model developed in chapter 5. As the aim of this thesis is to evaluate whether a mobility model based on autonomous mobility on-demand can provide sustainable mobility for Lower Austria, the designed model is also evaluated in respect to the three pillars of sustainable mobility. Finally, in chapter 6 a summary and conclusion is provided.

2. Autonomous vehicles

The first emerging trend in personal transport discussed in this thesis is the autonomous vehicle. The ability of an automobile to drive without human intervention is driven by advances in technology. Technology is taking over an increasing number of driving tasks such as lane keeping, speed keeping, parking or braking and are assisting human drivers in their driving. This development is incrementally transforming conventional vehicles into automated and ultimately autonomous vehicles, which no longer require a driver. Autonomous driving is therefore predicted to change the way we perceive and use personal transportation and to enable a new area of mobility.

2.1. Background and History

In general, autonomous vehicles operate in a very similar manner to humans driving a vehicle. Both have to collect information about their environment, process this information, make a decision and then act accordingly. To collect the information humans use their senses (eyes and ears). Similarly, autonomous vehicles use sensors, such as LIDAR, short range radar, GPS and cameras (ITF 2015). The processing of the information and steering is then done by software, control units and actuators (Pillath 2016), which act instead of the human brain.

The development of autonomous vehicles is largely driven by companies such as Google, Tesla and others. Governments, however, are starting to recognise the potential of autonomous vehicles and the inefficiencies of our current transport system too. Due to the high flexibility conventional automobiles offer, they have become a status symbol and have influenced the development of our infrastructure. However, instead of driving, cars are idle most hours of the day. They are either stuck in traffic congestion or parked. A study in Seattle found that only 11 % of vehicles are in use throughout the day, and when used there are only 1.6 people travelling in the car (Alessandrini, et al. 2015). This is highly inefficient and costly, and is now leading to a rethinking of transport systems. Further factors driving the development of autonomous vehicles and their impacts will be discussed throughout this chapter in more detail.

2.1.1. History

The vision of autonomous driving was born in the mid-20th century. A lot of research took place between the 1980s and 2000, but it took until 2004 for autonomous vehicle technology to significantly advance. Many researchers refer to the Grand Challenge organised by the US Defence Advanced Research Projects Agency (DARPA) as the acceleration point of autonomous vehicle technology. The Grand Challenge took place from 2004 to 2007 with the aim to demonstrate the feasibility of autonomous vehicle technology on a 150-mile route (DARPA 2007). The teams that participated were mainly from universities and businesses from around the world (Chow 2014). In 2004, no team was able to complete more than seven miles of the route. In 2007, the course was changed to a 60-mile route leading through an urban area (DARPA 2007). The competing vehicles had to master the route autonomously, follow traffic rules and deal with every-day-driving scenarios (DARPA 2007). In that year, six teams completed the challenge and demonstrated what autonomous vehicles were already capable of and how fast the technology was developing.

Since then, the development of autonomous driving and vehicles has further accelerated. At the time of writing, semi-automated features, like adaptive cruise control (ACC), lane departure warning, collision avoidance, parking assistant systems (PA) and on-board navigation are already incorporated into many sold vehicles (Fagnant and Kockelman 2013). These developments indicate that the vision of autonomous vehicles driving on our roads is close to becoming reality. How close we are will be discussed in the following chapters.

2.1.2. Levels of Automation

When talking about autonomous vehicles it is essential to understand what is meant with the term “autonomous vehicles”. In the media, as well as in research, autonomous vehicles are frequently referred to as “automated”, “highly-automated”, “fully automated”, “driverless” or “connected” cars (ITF 2015), (EPoSS 2015), (RAND 2014), (Alessandrini, et al. 2015), (Fagnant and Kockelman 2013) and these terms are used interchangeably. These terms indicate that the vehicles referred to have different abilities. To make clear which tasks of the driving process are performed by the vehicle and which tasks remain the responsibility of the human driver, The National Highway Traffic Safety Administration (NHTSA) and the International Society of Automotive Engineers (SAE), have both defined levels of vehicle automation.

The levels of automation defined by the NHTSA and SAE are based on the amount of dynamic driving tasks performed by the vehicle. The driving task comprises the steering, accelerating and braking of the vehicle, the monitoring of the environment, as well as decision-making (for example when to change lanes, when to indicate or use other signals) (Pillath 2016). The more of these tasks are performed by computer algorithms the higher the level of automation.

NHTSA (2013) has defined five levels of vehicle automation. These range from vehicles that do not have any automated control systems (level 0) to fully automated vehicles (level 4). This implies that with increasing level of automation the driver is less and less expected to monitor the environment while the vehicle is driving. In comparison to the NHTSA, the SAE (2014) identifies similar automation levels, with a difference being in the number of levels. The SAE namely classifies vehicle automation in six levels, which range from “no automation” (level 0) to “full automation” (level 5). It therefore distinguishes between "high" and "full" automation, which is classified as one level (level 4) by the NHTSA. The different levels of automations as defined by the SAE and the NHTSA are illustrated in table 1.

Table 1: Levels of automation adopted from ITF (2015)

	SAE Level	NHTSA Level	Name	Steering, acceleration, deceleration	Monitoring driving environment	Fallback performance of dynamic driving task	System capability (driving modes)
Human monitors environment	0	0	**No automation** The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems.				
	1	1	**Driver assistance** The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task.				Some driving modes
	2	2	**Partial automation** The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration / deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task.	 			Some driving modes
Car monitors environment	3	3	**Conditional automation** The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene.				Some driving modes
	4	4	**High automation** The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene.				Some driving modes
	5		**Full automation** The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver.				All driving modes

In both classifications a key distinction is made between level 2 (partial automation) and level 3 (conditional automation). This distinction is important as with level 3 the entire dynamic driving task is performed by the automated driving system. Before level 3, it is the task of the driver to actively monitor the environment at all times. From this point on, computer algorithms replace the human driver and the human driver is only expected to take over in exceptional situations. As a result, the human driver is more and more transforming to a passenger, who can sit back and relax or use the time in the car for example to read, make telephone calls, or answer emails.

Following the definitions of the SAE, the NHTSA and Pillath (2016), *automated vehicles* are vehicles that require a driver who is involved in the active driving process and include technology that offers assistance to the driver. Therefore, *autonomous vehicles* are what the SAE and NHTSA refer to as "fully automated" and what the NHTSA have defined as level 4 and SAE as level 5 automation. At this stage, all driving tasks are performed by the vehicle. For this reason, the British Department for Transport defines autonomous vehicles in more detail. Their definition highlights, that autonomous vehicles are vehicles "designed to be capable of safely completing journeys without the need for a driver in all traffic, road and weather conditions that can be managed by a competent driver" (Department for Transport 2015).

2.2. Connected Vehicles and Communication

The classifications of automation provided by the SAE and the NHTSA are very comprehensive. Nevertheless both miss to include "connected vehicles". A connected vehicle can be defined as "a motor vehicle equipped with devices to communicate with other vehicles or the infrastructure via the internet" (Pillath 2016). In other words, connected vehicles are vehicles that are able to exchange information with their surroundings. The exchange of information is either done via the internet or through local wireless networks. These networks allow the vehicles to interact with other vehicles (V2V), with the surrounding infrastructure (V2I) or with other devices (V2X) (Uhlemann 2015). This ability gives way to a new form of connectivity and automation.

It is important to note, that connected vehicles technology and autonomous vehicles technology are not directly reliant on each other. Both tend to use distinguished technologies that can be used without installing the other technology into the vehicle (Hong, Wallace und Krueger 2014). However, when both technologies are combined in one vehicle they have the ability to support each other and increase the benefits of both systems.

The development of wireless vehicle connectivity is especially driven by the rapid development of information and communication technologies, such as the mobile internet. The use of the mobile internet has significantly increased over the past years and has developed to an important asset in every-day life. People expect to have the same connectivity in their cars, as they have at home (Lu, et al. 2014). Connectivity, therefore, can already be found in cars in the form of Bluetooth and wireless LAN technologies, which work together with on-board infotainment systems, satellite navigation and smartphone-based connected-car solutions such as Apple's CarPlay and Google Auto Link (Murry 2015). In the future, connected vehicles will not only optimise their own operation, but also increase the comfort and convenience of their passengers and personalise driving.

Apart from communicating with the vehicle's external environment, connected vehicle technology also allows cars to communicate with their internal environment. Inside a car, an increasing amount of sensors are being installed, with the purpose to monitor internal processes (eg: tire pressure, water temperature in the cooling system) and to detect for example driver's fatigue (Lu, et al. 2014). The main purpose of the in-car sensors is to increase the safety standards of vehicles. At present, only a small number of these sensors are employed into cars sold. But predictions are that the number of sensors will reach 200 per vehicle by 2020 (Pinelis 2013), with the consequence of building an inter-vehicle communication network.

For connected vehicles to work effectively, a reliable and secure mobile communication network and intelligent transport system (ITS) is needed. The EU defines ITS as a system in which information and communication technologies are applied in road transport, including infrastructure, vehicles and users, as well as in traffic management (DIRECTIVE 2010/40/EU 2010). ITS, therefore, is the enabler of V2V, V2I and V2X communication. In order to build up a reliable and secure ITS in which connected and automated vehicles can operate efficiently, the European Commission, as well as the US Department of Transport (US DOT) are currently working on special ITS standards (European Commission 2015 c) (US DOT N.A).

Due to the various driving forces behind connectivity, it is likely that the levels of connectivity in vehicles will increase rapidly. Violeta Bulc, the EU commissioner for transport, said she "wants to see connected cars on European roads by 2019" (European Commission 2016). A fast growth of connected vehicles will also have a positive effect on autonomous driving. By introducing V2V, V2I and V2X technology into autonomous vehicles these will become more efficient and consequently safer.

This thesis will focus on autonomous vehicles, which are fully autonomous and connected. It is important to highlight that connected vehicles and autonomous vehicles complement each other and increase their positive impacts. This thesis considers connected vehicle technology as an essential technology, which should be paired with autonomous vehicles in order to achieve the full benefits autonomous vehicles offer.

2.3. Current Developments

During the Grand Challenge car manufacturers in joint action with University research centres were leading the field in autonomous driving technology (Anderson, et al. 2014). In the course of a few years, this appears to have changed. Companies, such as Google and Tesla are reporting considerable progress in the development and testing of autonomous vehicles and car manufacturers seem to be lacking behind. How far companies working on autonomous vehicles really are will be discussed in this part of this thesis. The analysis does not consider all companies working on automation of vehicles, as this would be out of the scope of this thesis. Therefore, this thesis focuses on companies that are either already very advanced in the development of autonomous vehicles or are important players in the automotive markets. In order to get a good understanding of the progress and possible deployment of autonomous vehicles, this thesis also includes the activities of governments in the analysis.

2.3.1. Autonomous Vehicles Today

The first company to start testing its autonomous driving technology on public roads was **Google**. With its Driverless Car Initiative, Google started developing its self-driving car technology in 2009 (Google N.A b) and has up to April 2016 driven 1.5 million miles with its test vehicles in autonomous mode (Google 2016 a).

At first, Google equipped a Toyota Prius and later on a Lexus PX450h with sensors, cameras and radars to test its software. The software senses location, traffic lights, other vehicles, cyclists, pedestrians, and is designed to improve how the car predicts and reacts to the behaviour of others. A driver is always present in these vehicles and has the option to take over the dynamic steering process. This type of test drive is considered as level 3 automation and has helped Google to develop its self-driving car prototype. Since 2014 Google is working on automation level 5 (Google N.A a). Google’s prototype has no steering wheel and pedals and therefore no driver. Instead the driving is fully handed over to the vehicle and people in the cars are only passengers. Figure 1 shows a picture of the prototype.

Figure 1: Google's self-driving car prototype (Google N.A b)

According to the monthly reports released by Google, up to the time of writing its self-driving cars have been involved in 21 accidents, of which none were caused by the Google car and no harm was caused to people (Google 2016 b). Google's aim is to build an autonomous car that "gets everyone around easily and safely, regardless of their ability to drive" (Google N.A a).

In contrast to Google, **Tesla**, an American electric automotive and energy storage company, has chosen a different approach in developing autonomous vehicles. Where Google has committed itself to build a car, which allows full autonomous driving, Tesla has chosen to provide software updates that equip Tesla vehicles with new automated features. In October 2015, Tesla released a wireless software update to its Model S vehicles, which were already equipped with sensors, cameras and radars (Tesla Motors Team 2015). The update included an automated driving system, called Autopilot, which can be categorised as level 2 and allows automatic steering, speed and lane changing, as well as parking services (Tesla Motors Team 2015). According to Tesla's CEO, Elon Musk, further software updates will follow and eventually allow Tesla to "end up with complete autonomy" (Korosec 2015).

While Google and Tesla have been following different approaches, both are working actively on pursuing their paths towards full automation. Traditional automakers, however, have appeared to be lacking behind in the development of autonomous cars.

Car manufacturers such as Audi even announced that it “will never build robot cars, but instead will always put the driver in the focus of its decisions” (Audi N.A). And Jim Lentz, CEO of Toyota North America, stated at the Automotive News World Congress in 2016, that Toyota believes “a human driver must always be behind the wheel” (Undercoffler 2016). These statements indicate that some automakers are not interested in developing autonomous vehicles.

This is, however, only partly true. All car manufacturers are working on different stages of autonomous driving, but they have been less successful in marketing their developments. Similar to Tesla, automakers have decided to slowly upgrade their vehicles with automated technology systems by adding new automated features to every new car release. Consequently, several autonomous driving features are already on the market, but are not perceived or marked as such. These features are commonly referred to as advanced driver assistance systems (ADAS). ADAS includes systems such as ACC, PA and Lane Keeping Assist Systems (LKA) (ITF 2015). These systems can be categorised as automated driving level 1.

Automakers, such as BMW, Mercedes, Audi, Nissan and Volvo have recently started to introduce level 2 features. This means that driving tasks such as parking, lane changing, stop and go in traffic jams, following traffic flows at low speed (below 30 km/h) are tasks that can be done by the vehicle itself with no human interference. This shows that automakers are working on autonomous vehicles, but are moving towards full autonomy in steps, as explained by Klaus Fröhling, member of the BMW management board (Boeriu 2015).

When full autonomy will be reached, however, is still unclear. Tesla’s CEO, Elon Musk, predicts that Tesla will be able to sell SAE level 5 vehicles by 2017 (Korosec 2015). In 2012 Sergey Brin, a co-founder of Google also predicted that autonomous vehicles would be available to the public in 2017 (Golem Media GmbH 2012). But in 2014, Chris Urmson, the director of Google's self-driving car program, announced that a commercial release of Google’s autonomous cars would take approximately until 2020 (Nelson 2015). Carmakers have announced that they are also working to reach highly automated by 2020 (BMW Group 2016) (Mercedes-Benz 2016) (Nissan 2014) (Audi N.A). However, these plans seem very ambitious. Navigant Research (2015) pointed out in a report that it is more likely that the automation level automakers hope to reach in 2020 will only be under specific circumstances and will still require supervision by a driver. Others are more cautious about these estimates. EPoSS (2015) stated in its report that level 5 automation will be released starting from 2025. The ITF (2015) and Fagnant and Kockelman (2013) expect full automation not until after 2030.

Before level 5 automation can be reached and fully automated vehicles can drive on our roads a number of challenges still have to be addressed. These challenges include technical and legal issues. At present, autonomous vehicles still face technical challenges when driving in unmapped geographic areas, on non-specific roadway types or in poor weather conditions, which influences the sight of the sensors and cameras (ITF 2015). For these conditions, special algorithms have to be written and comprehensive testing must be done (EPoSS 2015). Other challenges comprise data security, liability, ethics and legal issues and these are challenges the developers of autonomous vehicles cannot tackle alone. They depend on local authorities to support their efforts and to create suitable framework conditions for the development, testing and deployment of autonomous vehicles. Some countries have been more active than others in this task. Hence, this thesis does not discuss the additional challenges autonomous vehicles face, but examines what initiatives countries have taken to support autonomous vehicles technology.

2.3.2. Examples of Autonomous Vehicle Initiatives in Countries

The development of automated and autonomous vehicles is very much supported by countries. However, their efforts and approaches are very different. I have selected the United States, Japan, Singapore, Germany, the United Kingdom, Sweden and the European Union in general as illustration of different strategies. Their initiatives will be discussed in detail in this chapter.

2.3.2.1 The United States of America

The US Department of Transportation (DOT) has developed a national program for vehicle automation for 2015 to 2019. The aim of this program is to „position industry and public agencies for the wide- scale deployment of partially automated vehicle systems that improve safety and mobility and reduce environmental impacts by the end of the decade“ (US DOT 2015 a). The core of the program includes policy research and international research exchange, both focussing on all levels of automation, especially on the transition from level 2 to level 3 automation (US DOT 2015 a). This program is connected to the DOT’s research in the area of ITS, as the DOT has recognised that full vehicle automation can only be achieved if these are connected to each other and to the necessary infrastructure (US DOT 2015 b). To accelerate the initiatives of the DOT’s national program for vehicle automation, in January 2016, Barack Obama announced that he has allocated 4 billion USD for this program in his budget proposal for 2017 (NHTSA 2016).

To secure the US's leading position in autonomous driving several US states have already adjusted their regulatory framework. These now allow the testing and operation of autonomous vehicles on public roads. Nevada was the first to pass the necessary bill in 2012 (DMV 2012). California followed in September 2014 and at the time of writing, 12 companies are licenced to test their vehicles in California (DMV 2016). Other states, such as Florida and Michigan have followed (Buzzacco-Foerster 2016), (Michigan goverment 2013). Legally allowing autonomous vehicles onto roads is an easier task in the US than compared to Europe, as the US did not ratify the Vienna Convention of 1968.

The Vienna Convention states that "every moving vehicle or combination of vehicles shall have a driver" in Article 8 and continues that "every driver of a vehicle shall in all circumstances have his vehicle under control" in Article 13 (UN 1968). The driving of autonomous vehicles has therefore no legal foundation, which makes it difficult for the 36 countries[1] that ratified the convention to conduct tests of autonomous driving technology on their roads.

2.3.2.2 Japan

Although Japan's largest car manufacturer Toyota has been very reluctant towards autonomous vehicles, the government of Japan has behaved the opposite. Japan sees a big economic and societal potential in autonomous vehicles for its country. Autonomous vehicles can help Japan achieve economic growth and keep up the mobility of Japan's rapidly aging society. Hence, Japan wants to become the leader in autonomous driving technology and plans to showcase its advanced autonomous driving technology at the Olympic Games in Tokyo in 2020.

In order to achieve this goal, the Japanese Ministry of Land, Infrastructure, Transport and Tourism has set up an Automated Driving System Research Program to foster the research and development of autonomous driving systems and smart infrastructure (MLIT 2014). The ministry sees a strong linkage between autonomous driving and ITS and understands that one technology enables the other. Therefore, they stress the importance of developing both simultaneously. In 2013, Japan already installed 1600 ITS locations on its highways, which provide information and warnings on traffic (ITS

[1] All EU countries have signed and ratified the Vienna Convention, with the exception of the UK and Sweden who never ratify the treaty (UNTC 2016).

Japan 2012). Further steps are to follow in order to practically employ highly automated driving on Japan's highways by 2020 (EPoSS 2015).

2.3.2.3 Singapore

Compared to the US and Japan, Singapore is facing different challenges, which it hopes to tackle with autonomous vehicles. Being a city-state, land is scare in Singapore. The increasing population coupled with the increasing number of vehicles are putting pressure on the countries transport system. For this reason, the Land Transport Authority of Singapore (LTA) has decided to transfer its mobility systems towards sustainable mobility. This aim is also part of its "Smart Mobility 2030" program (LTA and ITS Singapore 2014). This program includes the commissioning of "the Singapore Autonomous Vehicles Initiative" (SAVI) in cooperation with the Agency for Science, Technology and Research. SAVI is a technology platform with the aim to investigate the opportunity and challenges of autonomous driving. This includes the research and development of autonomous vehicles, as well as ITS. The testing of autonomous vehicles started in the north of Singapore in January 2015 (LTA 2014).

Another initiative is the research conducted by the Singapore-MIT Alliance for Research and Technology (SMART), a research alliance of the Massachusetts Institute of Technology (MIT) and the National Research Foundation of Singapore. SMART is studying and testing the feasibility of autonomous vehicles in car-sharing concepts in Singapore. Their research suggests that a fleet of autonomous vehicles managed in a car-sharing concept can serve the entire population of Singapore and that this can be achieved by using only one third of the amount of vehicles currently driving in Singapore (Spieser, et al. 2014)

2.3.2.4 Germany

Germany is home to a number of car manufacturers, which are renowned for their advanced technology and high quality. It is, therefore, in the country's interest to make sure these companies retain their prominent position and can test their developments on public roads. Legally, Germany is bound by the Vienna Convention and cannot allow vehicles without a driver on its roads. In order to allow carmakers to test their automated driving technology, the German Ministry of Transport and Digital Infrastructure (BMVI) established a test field on the A9 highway in Bavaria (BMVI 2015 b). Mercedes-Benz is testing its autonomous lorries on this highway Mercedes-Benz is planning to change the transport sector by building autonomously driven lorries that use V2V technology to follow each other in 15-meter intervals (Thomas N.A). The first platooning tests have already been successfully conducted (Jaynes 2016).

The BMVI has also founded a round table for Automated Driving, which consists of politicians, representatives from insurance, automotive manufacturers and suppliers (BMVI N.A a). Its tasks are to discuss issues concerning legal frameworks, infrastructure and technological regulations for automated driving (BMVI N.A a). In addition, the Ministry for Education and Research is also funding research and development projects focused on electric and autonomous vehicles or ADAS (EPoSS 2015).

2.3.2.5 The United Kingdom

The government of the United Kingdom (UK) sees autonomous vehicles as major opportunity for its country. Similar to Germany, the UK has a large automotive sector and wants to secure the industry. But the UK has also understood that autonomous vehicles can bring potential economic, environmental and social benefits (Department for Transport 2015). Consequently, the government has been very active in promoting research, development, testing and deployment of connected and autonomous vehicles. An example for its early efforts are the Personal Rapid Transport (PRT) pod cars operating at Heathrow Airport. The battery-powered pod cars drive travellers from Terminal 5 to the terminal's business car park. The fleet consists of 21 fully automated pod cars, which can reach a speed of 40km/h and are in full operation since 2011 (Phenix 2014). As the pods are powered by electricity, they produce 50 % less carbon emissions per passenger than diesel-powered buses and even 70 % less emission compared with cars (Phenix 2014). A similar system has also been installed in the city Amritsar in Northern India (Phenix 2014).

To enable the development and deployment of more autonomous vehicle projects, the UK government has established the Centre for Connected and Autonomous Vehicles (CCAV). CCAV is a new policy unit with the task to bring together industry and academia and coordinate the government's activities in the area of connected and autonomous vehicles (GOV.UK 2016). One of CCAV's first projects was to review the UK's regulatory framework that applies to driverless vehicles. As the UK never ratified the Vienna Convention, it has an advantage over other EU countries and not a lot of changes had to be made to its legal framework. Testing of autonomous vehicles is, therefore, legal on public roads in the UK and not limited to test tracks nor need a permit (Department for Transport 2015). This is all laid down in the code of practice for autonomous driving tests, published by the UK government (Department for Transport 2015).

In addition, the government also created a technology and innovation centre, the Transport Systems Catapult, to drive and promote Intelligent Mobility. The Transport Systems Catapult is overseen by Innovate UK, the UK's innovation agency, which also manages the Intelligent Mobility Fund. The government has allocated 100 million GBP to the fund (Automotive Council UK 2016). Some of the money in the fund has been given to the winners of the "Introducing driverless cars to UK roads" competition launched by Innovate UK in 2014. The aim of the competition was to finance "collaborative R&D projects to research further how driverless cars can be integrated into everyday life in the UK" (Innovative UK N.A). The competition was won by four UK districts: Greenwich, South East London, Milton Keynes and Coventry (working together) and Bristol. These cities will test autonomous vehicles in everyday life for a trial period of 18 to 36 months (GOV.UK 2014).

The first trial started in Milton Keynes with three fully automated pods called the LUTZ Pathfinder. The LUTZ Pathfinder is a two-seater car pod powered by electricity, see figure 2, and which is being tested in pedestrian areas in Milton Keynes (Catapult N.A). Although the producer of the vehicle claims it to be fully automated, the pods still have a steering wheel and pedals for the trial period. The aim of the trial is to assess the technological and social feasibility of these automated pods (Catapult N.A).

Figure 2: Lutz pod (Catapult N.A)

A further eight projects have recently received funding from the Intelligent Mobility fund. Two of these projects are UK-CITE and Insight. UK-CITE project will test V2V and V2I infrastructure on roads around Coventry and Solihull, two cities in the centre of England (Robarts 2016). Jaguar Land Rover is involved in this project and will provide a number of test vehicles. In contrast, Insight will use the funding to develop driverless shuttles for pedestrian areas in cities. The focus of the project is on improving the mobility of disabled and visually impaired people (Robarts 2016). In summary, the UK initiatives are a very good example of successful government actions, which have managed to foster research and involve the national industry.

2.3.2.6 Sweden

The Swedish government together with the Swedish automaker Volvo has launched the joint initiative “Drive Me – self-driving cars for a sustainable future”. The idea behind the initiative is to jointly develop autonomous driving in Sweden and learn from each other. The Swedish government has understood that autonomous driving will have a major impact on its infrastructure and society and as consequence should be developed in cooperation (Swedish Transport Agency 2014). This is also the main objective of the project – understanding how self-driving vehicles will affect traffic flow, energy efficiency, safety and infrastructure. The project, therefore, involves a number of stakeholders: the Volvo Car Group also the Swedish Transport Agency, Swedish Transport Administration, The City of Gothenburg, Lindholmen Science Park and the Chalmers University of Technology (Volvo Car Corp. N.A. a).

Volvo will start testing it autonomous vehicles in 2017. Instead of having test drivers, Volvo has decided to let 100 customers test its vehicles on public roads in Gothenburg (Volvo Car Corp. N.A b). These customers will be testing the self-driving vehicles on selected roads in Gothenburg, which are typical for commuters and are very often subject to congestion.

The Drive Me project is only one example of the projects running under the newly established “Drive Sweden” program. The Swedish government set up “Drive Sweden” in 2015. The program’s vision is to make the Swedish transport system more sustainable by enabling automation and connectivity (Hellåker N.A).

A further advanced project and simultaneously a good example for a successful international cooperation, is the project Edgar. Edgar is an autonomous minibus for eight people designed to operate in cities. The minibus is powered by electricity, partly produced by the solar panels on its roof. It drives with a maximum speed of 40 km/h and is operated by a smart technology platform (Kilimann 2015). This smart platform manages the trip planning, registration of the users, ticketing and billing, as well as the routing of the minibus according to the present traffic situation. Testing of the project will start in the course of 2016 in Berlin. Edgar is a good example for a smart and sustainable mobility project developed by a group of engineers from Germany, Sweden and other countries.

2.3.2.7 The European Union

European cooperations such as Edgar are very much in line with the EU's Single Market Strategy, which involves the creation of a Single European Transport Area with common transport systems. This target is motivated by the vision to switch to a low carbon economy and close to zero traffic fatalities by 2050 (European Commisssion 2011), as well as decrease the Union's dependency on energy imports. In order to achieve these targets, the European Commission has established and funded a number of research and development projects to support the development of autonomous vehicles and ITS. A graphical overview of these projects can be found in appendix 1.

CityMobile2 is one of these projects. CityMobile2 is the successor project of CityMobile, which dealt with ITS for autonomous transport systems and took place from 2002 to 2008. The intention of CityMobile2 is to set up and implement a pilot platform for automated road transport systems (level 5) in selected European cities (Pillath 2016). The first trial was conducted in Oristano in Sardina, Italy, where electric autonomous vehicles were installed to transport passengers from the beach to their hotels (EPoSS 2015). The vehicles operated on separate road lanes, which were prohibited to other vehicles. Although this trial used autonomous vehicles, the concept is very similar to a railway, which limits the operation of the vehicles. Between 2012 and 2016, CityMobile2 will carry out several trials in nine European cities[2] (EPoSS 2015).

2.3.2.8 Comparison of the Initiatives taken by Countries

The analysis of the initiatives of the selected countries and the progress automakers are making in automation show a distinct picture. The endeavours to reach full

[2] Cern and Lousanne (Switzerland), León and San Sebastian (Spain), Vantae (Finland), Brussels (Belgium), Trikata (Greece), La Rochelle and Sophia-Antipolis (France), and Oristano and Milan (Italy).

automation follow two paths. The first path entails steadily increasing the amount of automated features in a vehicle. This way the driving tasks are slowly passed from the driver to the vehicle. Car manufacturers tend to follow this path and this approach reflects the levels of automation, as described in chapter 2.1.2.

The example of Tesla shows that this approach can bring some additional challenges. Other than Google, Tesla is already producing cars and has to keep up its car sales. Thus, their decision to gradually upgrade their cars by releasing new software updates for automated driving is economically reasonable. Such a software update was released in October 2015. It was first well perceived by Tesla's customers. But instead of increasing traffic safety, it has led to irresponsible driving, as drivers believed they could hand over the active driving process fully to the car (Berman 2015). This shows that drivers have to be well instructed how much of the driving task they can hand over to the car and when they can do so.

In contrast, the second path represents the path of those who have chosen to instantly develop fully autonomous vehicles (level 4). The deployment of the autonomous vehicles in this case starts in a specific area and is then slowly expanded. This path is the path of Google or projects like CityMobil2, LUTZ pod and the PRT in London Heathrow.

The results of this analysis highlight that these activities very often reflect strategic activities of countries. The US, the UK and Japan have all set theimselves the target to become a leader in autonomous driving technology. In comparison to these countries, Austria, which is not home to any ca rmanufacturers, is lagging far behind in its initiatives to support and enable autonomous vehicles on its roads. Austria only recently started looking into autonomous driving. In February 2016, the Austrian Ministry for Transport, Innovation and Technology (BMVIT) published "Austrian Research, Development & Innovation Roadmap for Automated Vehicles". The aim of this roadmap is to identify research and development areas Austria should focus on (BMVIT 2016). In the course of 2016, Austria also wants to publish its ITS strategy (BMVIT 2016). The establishment of these roadmaps and strategies are important steps, but as automakers are planning to release their first autonomous vehicles in 2020, Austria should actually be a few steps further ahead.

2.4. Impacts of Autonomous Vehicles

Autonomous driving is fundamentally different to human driving. Autonomous vehicles cannot fall asleep when driving, be distracted by mobile phones or get drunk. This section discusses some of the biggest potential impacts the introduction of autonomous vehicles could have on the economy, environment and the society. The economy, the environment and the society represent the three pillars of sustainability. I have chosen these for my analysis in order to identify the sustainable nature of autonomous vehicles. As the impacts of autonomous vehicles vary with the degree of automation, the analysis will concentrate on the impacts of fully autonomous vehicles.

2.4.1. Impacts on the Economy

Autonomous vehicles will have a significant impact on the economy. A number of positive impacts will be unlocked by decreasing accidents and improving productivity. Although the number of road accidents is decreasing, they still cause a significant amount of costs every year due to road damage as well as damages to vehicle and passengers. Increasing road safety is therefore an incremental goal of many governments.

Fagnant and Kockelman (2013), Litman (2015), and Dokic, Müller and Meyer (2015) highlight in their research that fully automated vehicles have a vast potential to decrease the number of car accidents and therefore increase safety on our roads. Wallace and Silberg (2012) even advocate that autonomous vehicles have the potential to develop to become a “crash less car”. These researchers base their argumentation on the fact that the main cause of road accidents is human error. The U.S. National Highway Traffic Safety Administration (2008) reported that 93 % of all road accidents are due to human error. This human error is in the majority of cases caused by alcohol, distraction, fatigue and speeding (Fagnant and Kockelman 2013). As autonomous vehicles cannot drink alcohol, get distracted by test messages, fall asleep or speed to impress others the number of fatal car accidents should significantly reduce.

It is clear that not all accidents can be prevented when switching to autonomous vehicles. For example, if a child suddenly runs onto the street, the autonomous vehicle may react quicker than a human driver, but might still not be able to stop in time due to the short stopping distance. Also, autonomous vehicles are not totally immune to error. Sivak and Schoettle (2015) identify vehicle failure and environmental factors like poor weather conditions as the major potential causes for accidents with autonomous vehicles. But research has also predicted that autonomous vehicle technology will with time learn to accurately respond to complex environments and could reach a fatality rate similar to aviation and rail and consequently have a vast impact on the economy (Fagnant and Kockelman 2013), (Dokic, Müller and Meyer 2015), (Smith 2015).

However, the risk of a technique failure such as a software failure still remains. It is therefore essential that car manufacturers take measures to minimise software failures and to set up mechanisms that come in force if such a failure occurs.

Apart from making road traffic safer, research also suggests that autonomous vehicles can eliminate inefficiencies in the use of our current traffic infrastructure. One of these inefficiencies is congestion. At present, traffic congestion is of concern in many cities and is causing passengers to waste their time in traffic jams. INRIX analysed the state of traffic congestion throughout Europe and the U.S. and found that in 2014 the congestion levels increased in the majority of European cities. They also found that in Austria a driver spends 24 hours per year stuck in traffic (INRIX 2014). The main reasons for traffic jams are inefficient use of lanes and intersections, insufficient road capacity and accidents. Technologies like ACC, V2V and V2I communication allow autonomous vehicles to travel closer together safely and therefore increase road capacity.

Shladover, Dongyan and Xiao-Yun (2012) found that the use of cooperative adaptive cruise control (CACC)[3] can increase the effective capacity of road lanes by 80 % as soon as the market-penetration of CACC reaches 90 %. Autonomous vehicles will also enable platooning. Platooning is the grouping of vehicles that travel in close proximity to each other (Bullis 2011). Research indicates, "the platooning of AVs could increase lane capacity by up to 500 %" (Fernandez and Nunes, 2012 as cited in (Silberg and Wallace 2012)). In regards to intersections, V2V communication allows more vehicles to utilise the green time at traffic lights (Fagnant and Kockelman 2013). When approaching an intersection, vehicles can communicate with each other and the surrounding infrastructure and coordinate their safe passage through the intersection. These increases in efficiency will lead to a smoothing of the traffic flow and will reduce travel times and consequently impact the productivity of people (Fagnant and Kockelman 2013).

[3] CACC is a combination of ACC and V2V communication (Shladover, Dongyan and Xiao-Yun 2012).

This elimination of the inefficient use of roads will help governments save money, as they do not have to invest in building additional traffic infrastructure. A report released by Bradlow and Jayachandra (2015) found that in the next 35 years Australia would have to increase its road network by 250 % in order to deal with increasing mobility demand. With the use of autonomous cars, the already existing lanes can be used more efficiently and Australia would have to increase its road infrastructure by only 50 %. The report also highlights that in the long run, when all vehicles can drive autonomously, the road capacity demand would decrease to the level in place today. This is based on the assumption that the number of drivers, road capacity, population and wealth do not change.

But in order to enable a widespread deployment of fully autonomous vehicles money will also have to be invested. A sector of investment will be the traffic sector itself. ITSs have to be installed in order to allow the communication between vehicles and with infrastructure. Japan has currently already installed 1,600 ITS spots and is leading the way. Further investments will also have to be made to secure a fast broadband internet. Autonomous driving will generate a significant amount of data, which has to be processed and transferred at high speed.

2.4.2. Impacts on the Environment

In Austria, the traffic sector was responsible for 21.7 Mt of CO_2 eq. in 2012 (Umweltamt 2014). The high CO_2 emissions are due to the increasing traffic on Austria's road and the dominant use of gasoline and diesel engine. Research suggests that autonomous vehicles have a number of benefits over conventional vehicles in energy use and can influence how vehicles are driven.

First, the concept of platooning allows autonomous vehicles to follow each other closely due to V2V communication. This allows the vehicles to maintain a constant speed, which allows optimal fuel combustion and reduces the aerodynamic drag. Together, these effects lead to fuel savings of 10 to 15 % (Bullis 2011) for passenger vehicles.

Secondly, autonomous vehicles improve vehicle operation as they reduce inefficiencies of human driving habits. For example, autonomous vehicles do not speed unnecessarily and avoid excessive stop and go. This leads to a smoother traffic fuel and results in energy savings of up to 15 % (Gonder, Earleywine and Sparks 2012).

Thirdly, V2X communication can provide real-time traffic information and help find the quickest route. This decreases travel time and congestion, as well as decreasing fuel use by 5 % (Wood, Gonder and Rajagopalan 2013).

Fourthly, V2V and V2I communication can also increase the amount of vehicles passing through at intersections. A constant flow of vehicles would eliminate the stopping and starting of vehicles, which can cause up to 40 % fuel use (Wood, Gonder and Rajagopalan 2013). By enabling cars to pass an intersection without stopping this energy is saved.

In summary, the energy savings achieved by autonomous vehicles add up to 70 to 75 %, which ultimately result in lower emissions. To conclude, the smoothing of traffic allows combustion engines to run in an optimal combustion zone and therefore minimise the amount of NO_x, HC and CO emissions (Olia, et al. 2015).

However, if switching to electric vehicles, these will further reduce the impact of transport on the environment. Compared to conventional vehicles electric vehicles do not produce any tail pipe emissions. How much emissions they produce during their life cycle depends on production and the electricity used to power them. A study conducted by Nealer, Reichmuth and Anair (2015) found that electric vehicles produce less than half of the emissions of a conventional car in their entire life cycle. By increasing the amount of electricity produced by renewable energy, the carbon footprint of electric automated vehicles can be further reduced.

2.4.3. Impacts on the Society

Once full automation has been reached and vehicles can drive from A to B without human intervention, transportation will be available to more people. People of all ages will be able to use autonomous vehicles and the need for a driving licence becomes obsolete (Brown, Gonder and Repac 2014). People, who want to use a car, will no longer have to prove that they possess the ability to drive a vehicle. Now that the car performs the driving, people using the car are solely passengers. This would be a big gain for elderly people. They would no longer have to rely on friends and relatives to chauffeur them to the doctors or to shops. Increasing or maintaining the mobility of people is an increasingly important issue. As life expectancy increases, the need for mobility will also increase. In order to not socially isolate these people it will be necessary to find solutions. Autonomous vehicles could be one of these solutions. Fagnant and Kockelman (2013) even suggest that with increasing autonomous vehicle experience, autonomous vehicles “may be permitted to legally chauffeur children”.

Increasing road safety by introducing autonomous cars will also highly impact society. Although private transportation has become significantly safer[4], cars are still considered more dangerous than any other means of transport. In 2014, 25,700 road fatalities were reported in the EU (European Commission 2015 b). By using V2V technology, cars that brake can communicate this to its surrounding vehicles and allow these to react accordingly. Another possibility to decrease road fatalities is by equipping cars with new safety features, such as eCall. eCall is an in-vehicle system with the aim to alert rescue services automatically in the case of a road accident (Uhlemann 2015). The system is an initiative of the European Union, which hopes to save lives and the severity of injuries by getting rescue services to the scene of the accident quicker than before. The European Parliament has passed a EU regulation on 28 April 2015, that foresees that by April 2018 all new cars have to be equipped with the eCall system (Uhlemann 2015).

Research found that young and elderly people are particularly vulnerable to traffic accidents. In 2014, 17% of road fatalities were people between 15 to 24 years old (European Commission 2015 b). The WHO even reported that traffic accidents were the main cause of death for this age group (World Health Organization 2013). The share of elderly people killed in road accidents is also increasing. This is of increasing concern as the number of elderly people is expected to continuously increase in the future. Increasing road safety is therefore a major goal all around the world[5]. According to The Economist (2015), Fagnant and Kockelman (2013), Litman (2015), and Dokic, Müller and Meyer (2015) autonomous vehicles can help achieve this goal.

3. Mobility On-Demand

Mobility on-demand is another emerging trend in transportation. Similar to autonomous vehicles, on-demand mobility is enabled by recently available technology and changing the way we use transportation. Mobility on-demand can be defined as “the use of shared vehicles accessed on demand” (Greenblatt and Shaheen 2015). A fleet of vehicles is deployed in a designated area. Customers wanting to use a vehicle can do so by using a smartphone application (app) to reserve or hail a vehicle. The big

[4] In 2014 the number of people killed in road accidents was 18 % less, than in the year 2010 (European Commission 2015).
[5] The EU, for example, has set itself the goal to halve the number of people killed in road accidents from 2010 to 2020 (European Commission 2015).

advantage of mobility on-demand services is that the service can be accessed spontaneously and latency is short (Rayle, et al. 2014).

To get a good understanding of how mobility on-demand is influencing transportation, this thesis will discuss the different forms of mobility on-demand, current development and trends in this section. Special focus is also on potential impacts of mobility on-demand on the economy, the environment and the society.

3.1. Background and History

As described in the introduction of this thesis, private automobiles have shaped our mobility system and have led to an unsustainable and inefficient use of private mobility. Moreover, the majority of vehicles used at present are "over-engineered and underutilised" (Pavone 2015). Automobiles are designed to have more than 100 PS[6] and could transport approximately five people (Statistik Austria 2016). A number of surveys however found that the majority of people only drive 14.7 km per day (Herry Consult GmbH 2012) with a vehicle occupation of 1.6 people (Alessandrini, et al. 2015). Furthermore, private automobiles are idle most of the day, as they are parked 90 % of the day (Alessandrini, et al. 2015). As a result, private vehicles have reached their limits to sufficiently settle the demand for personal mobility (Chong, et al. 2013).

Out of the motivation to make personal transportation more sustainable and efficient, mobility on-demand systems have developed. Mobility on-demand systems work for cars, as well as for car rides, bicycles and other transportation modes and have found their application mostly in cities in the past years. The growth of these new mobility models is strongly connected to the growing sharing economy, which promotes the renting of goods and services. In regards to cars, mobility on-demand is typically classified into three different forms: carsharing, ridesharing and ride-sourcing. As the focus of this thesis is on personal vehicles, these three forms will be discussed in the following sub-chapters.

3.1.1. Carsharing

Carsharing is currently the most widespread form of mobility on-demand services. The principle of carsharing is very simple: People can use private vehicles without the cost and responsibility of owning a car. Instead, they can use the vehicles on an ad hoc

[6] In 2015, 60 % of all new registered vehicles had more than 100 PS in Austria.

basis and according to their demand. Hence, carsharing is a car rental service of shared vehicles for a short term only, which can range from a few minutes, one hour, a day or more depending on the organisation of the service. Carsharing services are in general organised by commercial businesses, public agencies or cooperatives.

There are two distinct models of carsharing: round-trip carsharing and one-way carsharing. Round-trip carsharing is a mobility on-demand service where users have to return the vehicle to its origin at the end of their rental (Le Vine, Zolfaghari and Polak 2014). The largest provider of round-trip carsharing is Zipcar. But also many cooperative carsharing services are based on the principle of round-trip carsharing (Shaheen, Mallery and Kingsley 2012). In contrast, one-way carsharing allows users to release the car from its rental in a different area than it was picked up. This makes carsharing more convenient for their users. But it also demands for more organisation as the vehicles may spread according to their use in a city and this leads to an unbalanced distribution. This form is therefore limited either to a designated area (in this case it is called “free-floating” carsharing) or it is station-based, which means that the vehicles are pick up and returned to specific carsharing stations (Le Vine, Zolfaghari and Polak 2014).

The goal of carsharing is to provide a flexible and cheap alternative to private vehicle ownership and therefore reduce the negative externalities of private vehicle ownership (Shaheen and Cohen 2015). The sharing of the vehicles also leads to a more efficient use of vehicles, reduces the need for parking and ultimately reduces the number of cars in cities. Carsharing is also used as supplement to other means of transportation, thus it can help to solve the first and last mile problem (Pavone 2015). Consequently, it can be concluded that carsharing is a first step toward vehicle autonomy and increases the access to personal mobility.

The concept of carsharing was developed in Europe in the 1940s. But it took until the 1980s for it to become popular and then finally spread to North America and Asia in the 1990s (Shaheen 2013). What started in neighbourhoods and on university campus and was organised mainly by cooperatives, was eventually developed to a business model by car manufacturers. Car manufacturers saw a new business potential in carsharing and also had enough capital to set up the necessary fleets. The biggest commercial providers are Zipcar, owned by Avis, car2go, owned by Daimler AG, DriveNow, owned by BMW, and Multicity Carsharing, which is owned by Citröen. Their joint efforts made carsharing big. According to the latest research by (Shaheen and Cohen 2015), carsharing is deployed in 33 countries, in more than 1,531 cities worldwide and has approximately 4.8 million members. In Austria, car2go had 60,000 users solely in Vienna in 2014 (car2go 2014).

3.1.2. Ridesharing

Ridesharing, also known as carpooling and vanpooling, is concerned with the sharing of a car or van for a trip with similar origin and destination. The difference between carpooling and vanpooling is the type of vehicle and consequently the number of passengers. Carpooling is a form of ridesharing, which uses a private car and can transport a maximum of seven people, whereas vanpooling is the use of a shared van where seven to 15 people can travel together (Chan and Shaheen 2012).

Ridesharing is mainly motivated by economic benefits. Instead of driving to work alone with a car full of empty seats, the driver can offer these seats to others and therefore split the travel costs, for example fuel costs. But ridesharing can also lead to societal and environmental benefits. As more people share a ride, vehicle traffic will decrease, which will ease congestion, lead to travel time savings, increase energy security, decrease the need for parking and ultimately reduce GHG emissions (Viechnicki, et al. 2015).

According to Shaheen et al. (2015) there are three different categories of ridesharing. First, acquaintance-based ridesharing involves the grouping of friends, co-workers or family members in a private car. Second, organisation-based ridesharing requires the participants to be members and therefore they have to sign up for example on the organisation's website. Third, ad hoc ridesharing is related to casual carpooling, which is known in the US as "slugging" and in Europe as "hitchhiking".

Ridesharing has a long history in North America, where it began in the 1940s. People were encouraged by the government to share rides in order to help conserve oil resources for America's participation in the Second World War. During the oil crises in the 1970s ridesharing had its peak in the US. 20.4 % of American workers used carpools to commute to work (Shaheen, et al. 2015), which was beneficial to reducing the country's petroleum consumption. Since then the participation in ridesharing services has "declined to a low of 9.3 % as of 2013" (Shaheen, et al. 2015), but it is experiencing a renaissance.

It should be emphasised that ridesharing services are non-profit services and that the car driver determines the destination of the trip and not the passenger. This distinguishes ridesharing from ride-sourcing, which will be discussed in the subsequent chapter.

3.1.3. Ride-sourcing

Ride-sourcing is the third and newest form of mobility on-demand services and has its roots in ridesharing, which it is often confused with. Different to ridesharing, ride-sourcing provides a commercial service of on demand or rearranged ride services (Greenblatt and Shaheen 2015). Drivers and customers are matched via an online platform, which can be accessed via smartphone apps. The platforms include rating systems for the driver and passenger and calculate the approximate price of a trip beforehand (Rayle, et al. 2014). Once a customer and a driver of a vehicle are matched, the driver picks up a passenger and drives him or her to his or her desired destination. Different to ridesharing, the driver of the ride-sourcing car is paid, which offers the driver a source of income, and the passenger is the one that determines the destination of the trip.

Ride-sourcing is therefore comparable to a taxi service, with the difference that ride-sourcing "enables more efficient use of vehicles that drivers already own" (Rayle, et al. 2014). Rayle et al. (2014) also point out that ride-sourcing services are more reliable than traditional taxis due to their matching platforms, their low prices and rating systems. Hence, ride-sourcing services, also known as Transportation Network Companies (TNC) are becoming an increasing competition to taxis and in addition challenging regulations and public policies (Rayle, et al. 2014).

3.1.4. Communication: Mobile meets Mobil

The development of mobility on-demand has been largely driven by the internet and mobile technology. Mobile technology enables people to access the internet via their smartphone or other portable devices and allows them to obtain real-time information according to their location. This freedom of communication and connectivity has led to a worldwide increase in mobile internet usage. In 2015, the worldwide penetration of mobile phone internet users was slightly over 50 % (statista 2016). By 2017, this figure should increase to 63 % (statista 2016), showing the fast spread of the mobile internet. It is becoming an integral part of people's daily life.

The ability to obtain real-time and location-based information has transformed a number of industries and is now also changing the way people use transportation systems. For example, apps, such as Google maps or special trip planning apps are making it easier for people to find their way around and use public means of transportation (Goodall, et al. 2015). They are, therefore, influencing the choice of transportation and decreasing travel time. Consequently, the use of mobile technology is making transportation more intelligent, more efficient and more tailored to personal needs, which in the long term lead to a change in consumer behaviour.

Changes in consumer behaviour due to mobile technology have already affected hotels, airlines and other travel companies. The automotive and public transportation sector is next and research predicts that the impact of mobile technology is going to be even more disruptive. Digitalisation will not only affect mobile services, but also vehicles and infrastructure. Goodall, et al. (2015) name five trends in mobility services due to digitalisation: 1) mobility services will become more user-centred 2) transportation will be integrated and intelligent 3) digitalisation will change pricing and payment of mobility services 4) Digitalisation will result in automation and more safety 5) public and private innovation will be fostered.

3.2. Current Developments

Advances in mobile technology are also enabling the development of mobility on-demand services and are further shaping the way personal mobility services are developing. For example, **ridesharing** services, especially organisation-based ridesharing services, are experiencing a sort of renaissance. Together with the high oil prices in 2005, followed by the financial crises in 2008 and the development of smartphones, this has increased the interest in ridesharing again, and which has led to the creation of new ridesharing services (Greenblatt and Shaheen 2015).

Examples for these new services are “Mitfahrgelegenheit” in Germany, “bla bla car” in the UK and “Zimride” in the US. These online platforms match drivers, who travel from A to B and have free seats in their car, with travellers that would like to share a ride. With the use of smartphone apps, the location of both can be detected, and driver and passengers can easily and quickly communicate with each other to enable in real-time ridesharing. Real-time ridesharing, therefore, provides a great flexibility.

In the case of **ride-sourcing**, this is a mobility on-demand service that has only developed recently and mainly through the use of smartphone apps. Companies such as Lyft, Sidecar, and Uber offer on-demand trips within cities. Passengers that need a ride are linked with drivers that have a car via smartphone apps. Apart from sourcing a ride, Lyft, Sidecar and Uber also offer customers to share a ride with another customer that is travelling in the same direction and lets the passengers split the costs. These services have been launched under the names “Lyft Line”, “Sidecar Shared Rides”, and “uberPOOL” and are at the moment of writing available in the US, a few cities in Europe as well as in Bangladesh and India (Uber Newsroom 2016), (Kokalitcheva

2016). According to Kokalitcheva (2016), 40 % of all Lyft rides are already shared rides.

The smartphones apps developed and used by ride-sourcing companies can be defined as **e-hailing** apps. E-hailing is the electronic version of hailing a ride. Instead of standing next to the street and physically hailing a taxi or any other form of transportation, e-hailing allows customers to do this via an app (Greenblatt and Shaheen 2015). This allows customers and drivers to be matched in real-time and increases comfort and efficiency. Uber and other ride-sourcing companies were the first to offer e-hailing apps. Traditional taxi services have now followed and are offering e-hailing apps in order to keep up with the increasing competition they are facing. E-hailing apps can either be maintained by the taxi or ride-sourcing company or by a third-party provider (Shaheen, et al. 2015). Popular third-party apps in Austria are "myTaxi", "taxi.eu" and "TaxiMapp" (Zimmer and Pripfl 2014).

In the last century, cars were considered a status symbol and mobility on-demand services were rarely used. Instead of saving money and reducing CO_2 emissions, people favoured owning a car over sharing one (or sharing a ride). Today, attitudes have changed and people seem more open to new mobility concepts, which are closely related to the sharing economy. The increasing popularity of sharing models is supported by the findings of recent studies that indicate that the status of cars is fading. Landmann, Hasenberg and Weber (2011) state in their "Young Mobility Survey" that there is a shift in viewing cars and that these are increasingly being seen as simply a means of transport. This means that for young people it is important to get from A to B, but it does not matter how. Their attitude towards cars is changing. This change in attitude can also be seen considering that more young people increasingly wait until they are in their 20s before getting their drivers licence (Sivak and Schoettle 2012) and that mobility on-demand services are gaining in popularity.

The popularities of carsharing, ridesharing and ride-sourcing have very different levels, as shown in figure 3. This figure was published by Viechnicki et al. (2015) and shows how the different forms of mobility services have grown in the past years. Ridesharing, which is displayed in the figure as carpooling, has grown the least. As reason for this poor development Viechnicki et al. (2015) name the lack of incentives for customers and providers to participate and develop this service. In comparison, carsharing services show a steady growth. This is due to the strong participation of car manufacturers, which are constantly developing this form of mobility. The biggest expansion, however, was in the sector of ride-sourcing, what Viechnicki et al. (2015) define as on-demand service. Within a few years, this sector has managed to rapidly evolve and is now on the edge of being an "early adopter" phenomenon to reaching a critical mass.

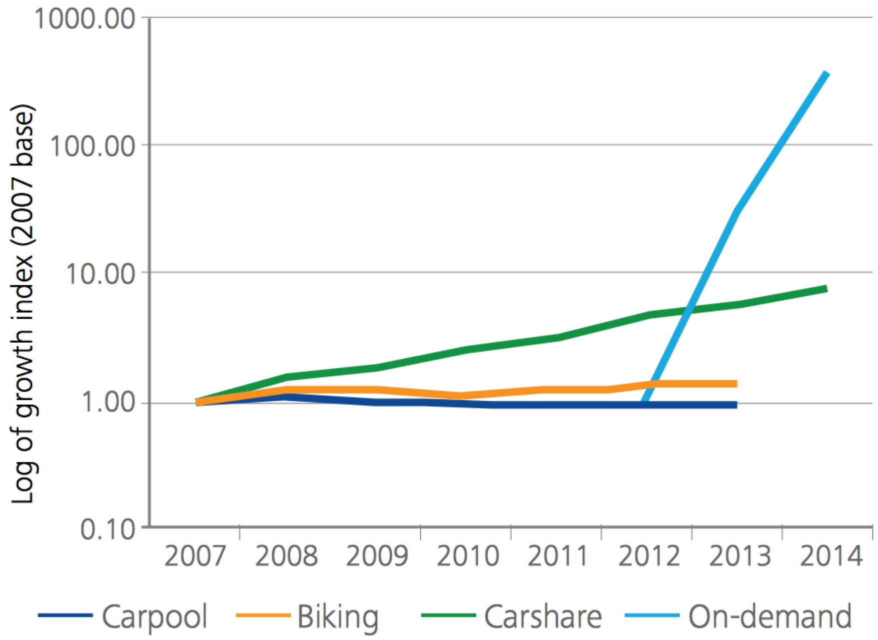

Figure 3: Growth rates of mobility on-demand services (Viechnicki, et al. 2015)

As shown in figure 3 the two most successful mobility on-demand services are carsharing and ride-sourcing. In the following chapters the most prominent representative of these two mobility forms are analysed in more detail. The aim of the analysis is to identify their success factors and limitations as well as to evaluate whether these models are suitable for rural areas.

3.2.1. Car2go

Car2go is the world's largest provider of one-way carsharing. Established in 2009, it is an affiliate of Daimler AG, which operates in cities across Europe and North America. The car2go fleet consists of Smart Fortwo vehicles, which are powered by gasoline or electricity[7] and ideal for urban traffic (car2go Österreich GmbH 2016 a). To rent a car2go vehicle, customers have to first register online on the company's website, download the car2go app and then go to a validation point, where car2go checks their ID and driving licence (car2go Österreich GmbH 2016 c). The document check is a necessity and threshold to making the registration process easier. But after this

[7] At the time of writing, car2go offers electric vehicles in selected cities. These are for example: Berlin (Germany), Madrid (Spain), Amsterdam (Netherlands), Portland, Vancouver (Canada), San Diego and Austin (USA).

process customers are free to use the car2go vehicles on their demand. In Europe, they can even use the car2go vehicles in all European cities, where car2go operates. Unfortunately, this is not the case in North America, where customers can only use the service in the city they registered.

A key element in car2go's rental service is the car2go app. With the app customers can find their nearest car2go vehicle, reserve the vehicle, report a damage, look up information about parking spaces and garages or find their nearest gasoline or charging station (car2go Österreich GmbH 2016 c). Since November 2014, the vehicles can also be unlocked with the app (Blanco 2014). The customer simply has to enter his or her pin-code together with the vehicle number and then the car opens its doors (car2go Österreich GmbH 2016 c). By adding this functionality to the app, car2go could slowly eliminate the member cards with an imbedded RFID chip that unlocked the cars and switch to a smartphone based rental service. This makes it easier for customers to use the carsharing service, as all they need is their smartphone, which the majority of people carry with them all the time.

Another important element of car2go's carsharing service is the fact, that their customers can rent a car whenever they need one, but do not have to maintain it. The one-way car rental service allows point-to-point carsharing and therefore allows a high flexibility to use car2go whenever customers need a car and to reach any desired destination in the company's coverage area. This flexibility is further underlined by the company's pricing scheme. As the rental service is charged either by minute, by hour or by day it allows to efficiently meet the user's needs (car2go Österreich GmbH 2016 b). In regards to maintenance, car2go has a service team that regularly cleans, refuels and services the fleet and therefore takes over this burden that comes with car ownership. To keep the workload manageable, car2go has introduced an incentive system for customers to refuel vehicles, when the tank is less than a quarter full[8] (car2go Österreich GmbH 2016 c). Together, these factors offer a high level of independency to the carsharing users, which can be considered a form of autonomy.

But car2go also has its limitations. First of all, the service can only be accessed by holders of a driver's licence. People who do not have a driver's licence or are not capable of driving (due to their age of physical abilities) are excluded from the service. Next, the service is only available in the company's coverage area. This restriction is a requirement one-way carsharing companies have to make to insure that their fleet is not distributed over a too wide area and vehicles don't remain idle for too long. This shows that the service only works if the vehicles are in regular use, there is a balanced

[8] Customers, who refuel the car at one of the partner gasoline stations of car 2go receive free rental minutes (car2go Österreich GmbH 2016 c).

distribution and if a certain density of population, hence users, is given. For this reason, carsharing services are only deployed in urban areas. Finally, carsharing services can only operate in cities with enough parking spaces. If parking spaces are limited in a city, the free-floating system simply does not work.

3.2.2. Uber

Similar to car2go, Uber is a successful provider of a mobility on-demand service, with the difference that it offers a ride-sourcing service. Uber started offering its service in 2009, and claims to be a smartphone based, affordable ride-sourcing service (Uber N.A. a). Within a few years, Uber managed to develop from a small start-up company to a company that operates in 300 cities worldwide and is valued at 45 billion EUR (Newcomer 2015). Despite the controversies and opposition against Uber, Uber is the only ride-sharing platform that has managed to establish itself so successfully that its drivers are even outnumbering local taxi drivers in specific cities [9] (Ahsan and Hensley 2015).

Uber's success is tied to the simplicity and customer orientation of its service. To use Uber, customers have to register online or via their smartphone app. The registration process is simple, but requires a credit card as Uber is a cashless service that charges all trips to the customer's credit card (Uber N.A. b). Once registered, the on-demand service is ready to use. The customer simply has to open the app, set his or her pick up location and request a ride. The app then connects the customer with the closest free Uber driver by using their GPS data (Uber N.A. b). When entering the destination, he or she even receives a price estimate for the trip.

In addition, the app allows an additional set of function to meet its clients' needs. First, customers are able to view the profile of the Uber drivers, view their licence plate and ratings and rate the drivers themselves (Uber N.A. b). This function allows a certain degree of quality control and safety measure for the customers. Second, passengers can share their route per text message via the app. This service has been integrated to increase the customer's safety (Uber N.A. c). Third, Uber offers passengers travelling together to split the fare. This feature can also be activated via the app. In sum, these functions show that the smartphone app is a central part of Uber's mobility service.

[9] Cities where Uber has outnumbered local taxi drivers are for example London, UK and Sydney, Australia (Ahsan and Hensley 2015).

A further advantage of Uber's ride-sourcing service is that it is available to all people (who have a credit card). To use the service, people do not need a driver's licence or have to be physically capable of driving, as the driving is done by the Uber driver. The service is also available to people traveling in a group, as it offers vehicles in different sizes and to people with special needs. People with special needs have the option to select a vehicle that is accessible with a wheelchair, when booking a trip (Uber N.A. b). This is a big advantage over car2go and taxi services and may explain the rapid growth of Uber and other ride-sourcing services as illustrated in figure 3 (page 32).

Uber also has found a way to settle the needs of hedonic drivers. It does this by offering vehicles in different luxury classes. Depending on the occasion and preferences, passengers can choose whether they want to ride in a normal vehicle or in a limousine, SUV or another premium car. This service is similar to classic car rental services that also offer different car classes for rent.

To complete, Uber is a service that uses the vehicles that are already available in a city. The Uber drivers are private people that use their private vehicles to driver people from A to B. This allows Uber to make use of an already available source, to utilize these more efficiently and to not creating additional vehicles.

But ride-sourcing services such as Uber also have their limitations. Similar to car2go, Uber also works best when applied in an urban area. This has several reasons. First, to ensure a minimal waiting time, the service needs a sufficient amount of available drivers. Further, drivers have to be available round-the-clock to provide an attractive mobility service to passengers. On the other hand, the demand for Uber rides should be high enough to offer drivers an attractive and reliable income. Uber, therefore, has a supply and demand problem. It has started offering its service also in rural areas in the US, but with only little success so far (Hawkins 2015). Furthermore, the drivers represent a significant pool of costs for Uber. From the fare Uber charges a passenger for a ride, Uber earns 20 to 30 % and the remaining 70 to 80 % are the driver's income (Rayle, et al. 2014). This shows that the driver is the limiting factor of ride-sourcing.

3.3. Impacts of Mobility On-Demand

In order to understand whether mobility on-demand services have the potential to provide sustainable mobility, this thesis analyses the impacts the services will have in regards to the three pillars of sustainability (economy, environment, society). Due to the novelty of some mobility on-demand models research is scarce in some fields and mainly concentrated on carsharing and ride-sourcing.

3.3.1. Impacts on the Economy

To the economy, mobility on-demand is going to be disruptive. Research has found that carsharing is changing car ownership and the way people think of it. According to a survey conducted by Martin and Shaheen (2011) every fourth carsharing user sold their private vehicle and every fourth postponed purchasing a new vehicle. The same survey concluded that single households are most likely to give up their car, followed by households that have two cars and give up one of them due to carsharing. Shaheen and Chan (2015) suggest that one carsharing vehicle can replace nine to 13 private vehicles. This shows a clear change in attitude towards private vehicles and indicates that carsharing has to potential to provide the same mobility as private transport.

The impacts of ridesharing and ride-sourcing on car ownership are less studied and not well understood at present. One of the few studies in this regard was conducted by Rayle et al. (2014). They found that 40 % of ride-sourcing users reduced the use of their personal vehicle due to services such as Uber and Lyft. This is a significant number and indicates the popularity of the service. Rayle et al. (2014) therefore conclude that ride-sourcing provides "an attractive alternative to driving and these services can potentially reduce auto use [and] ownership". The reduction of car ownership will have a disrupting impact on the automotive companies and connected industries.

Mobility on-demand will also help get rid of inefficiencies in personal transport. Ridesharing services, for example, make use of the empty seats and allow people to share rides with other passengers travelling in the same direction. This increases the efficiency of a vehicle and leads to savings in fuel and travel costs. Furthermore, the sharing of rides decreases vehicle traffic as fewer cars can serve more people. According to Viechnicki et al. (2015) it can decrease vehicle kilometres travelled (VKT) by up to 30 %. A decrease in vehicle traffic will furthermore ease congestion, decrease travel time and enhance productivity. Removing cars will also mean fewer accidents and fewer costs for road construction (Viechnicki, et al. 2015). This will generate savings for municipalities.

Time savings will be another impact of mobility on-demand systems. Rayle et al. (2014) state that ride-sourcing services provide substantially shorter waiting times than conventional taxi services. These savings in waiting time will further increase with increasing connectivity of transportation services, which will improve e-hailing and other smartphone based services.

Dispite the disruptive nature of mobility on-demand this personal transportation model also holds the potential of new business models. Mobile technology facilitates the establishment of new business models as it makes it easier to bring together customer and supplier. Companies such as Uber and car2go demonstrate how successful and fast new business can grow.

3.3.2. Impacts on the Environment

Mobility on-demand systems will play an important role in mitigating the negative effects of personal transportation on the environment. The reduction in vehicle ownership discussed in the previous chapter will also lead to a reduction in VKT and GHG emissions. Shaheen and Chan (2015) found that carsharing can reduce GHG emissions by 34 to 41 % per year and household. Similar numbers are also suggested by earlier research conducted by Shaheen, Cohen and Darius (2006). They report that carsharing users reduce their annual VKT by about 30 % in Europe and by about 40 % in the United States. A report released by the International Energy Agency estimates that in 2006 the worldwide amount of CO_2 reduction achieved with carsharing was around 217 kt of CO_2 (IEA 2009). According to the IEA (2009) an increase of carsharing users to 25 million would allow one carsharing vehicle to replace six vehicles, which would result in a reduction of 11,861 kt of CO_2 emissions in one year. This is the same amount of CO_2 emissions Portugal produced from fuel combustion in 2013 (IEA 2015).

Research also found that the reduction of car ownership leads to an increase use of public transport and walking. In North America, 12 to 54 % of carsharing members increased their walking after joining a carsharing service (Greenblatt and Shaheen 2015). Furthermore, it was reported that 30 % of urban traffic is caused by people looking for a parking space (Shoup 2006). This traffic can be removed by a switch to ride-sourcing and ride-sharing, which will result in fuel savings and consequently less GHG emissions.

Additional savings in GHG emissions can be achieved by switching to electric vehicles in mobility on-demand services. At least, it will eliminate the tail pipe emissions. How big the exact savings will be depends on the source of electricity. If electricity is produced from renewable sources, carbon emissions will be eliminated to a great extend (Mitchell, et.al 2008).

3.3.3. Impacts on the Society

The establishment of mobility on-demand models will have its biggest impacts on society. As discovered in the previous chapter mobility on-demand makes the ownership of private vehicles obsolete. People will no longer have to pay for car insurance, taxes, depreciation, parking, fuel or service costs. Instead they can use private transportation on demand and pay according to their use. This will significantly decrease the costs of mobility. Research gives an estimate how high the savings will be. Shaheen and Chan (2015) found that a carsharing member in the US saves between 154 to 435 USD per month. Mitchell, et al. (2008) compared in their study the costs between private mobility and mobility on-demand systems. They found that for the same mobility a person that used of mobility on-demand services only paid 45 % of the costs the person would paid if he or she used private mobility.

Besides decreasing mobility costs, mobility on-demand will also increase mobility. Services such as carsharing and ride-sourcing give people access to vehicles without bearing the costs of vehicle ownership. This has substantial benefits for people with low income and people that only occasionally need a car. Furthermore, mobility on-demand has the potential to extend the draw area of public transport (Shaheen, et al. 2015) as it can provide transportation for the first and last mile. In addition, it can provide transportation in areas where public transport is scarce.

3.4. Trend: Autonomous Mobility On-Demand

As identified in the previous chapters, mobility on-demand systems are gaining in popularity due to their customer orientation, their simplicity in using the service and their availability on demand. But there are also a number of challenges and limitations current mobility on-demand systems face. For example, carsharing has to make sure that their vehicle distribution is balanced to insure that vehicles are available and in short walking distances when demanded. This can be a big challenge, especially for one-way carsharing, when the demand is high and concentrated in specific locations. Car2go addresses this issue by redistributing their fleet themselves. They have staff that drives vehicles to high-demand and vehicle depleted locations (Chu 2013). This, however, costs money and cannot be done on a regular basis as otherwise the costs for the carsharing service would become unsustainable.

In the case of Uber, the driver is the limiting factor. If Uber does not have enough drivers, it cannot offer its service. At the same time, it has to offer the drivers attractive earnings and wants to increase its own profit. Hence, it is a balancing act for Uber to decide on its commissioning structure.

A possible solution to these issues is autonomous driving. Research suggests that, by applying autonomous vehicles, carsharing companies will be able to rebalance their fleet themselves without employing drivers (Spieser, et al. 2014). The vehicle will be able to autonomously drive to customers, to charging stations or service centres (Pavone 2015). Consequently, as autonomous vehicles take over driving tasks, the need for a driver is eliminated, which will especially benefit ride-sourcing companies. They will be able to offer their service at cheaper rates and potentially increase safety. In addition, autonomous vehicles will allow all mobility on-demand services to offer personal door-to-door transportation. Customers will be picked up at the origin of their trip and dropped off at their desired destination (Chong, et al. 2013) and potentially provide unrestricted access to personal mobility. As a result, autonomous vehicles can play an important role in advancing the services of mobility on demand companies, making it available to more people and potentially changing the way we perceive and use personal vehicles.

As the synergy of autonomous vehicles and mobility on-demand is a relatively new research area, literature is sparse and only a small number of studies have been conducted to analyse the potential impacts on our transport system. It therefore does not come as a surprise that different terms are used in literature for the same concept. For example, Pavone (2015) and Speiser, et al. (2014) uses the term autonomous mobility on-demand systems. Whereas Fagnant and Kockelman (2013), Greenblatt and Shaheen (2015) and Zhang, et al. (2015) talk about shared autonomous vehicles. Burns, Jordan and Scarboroug (2013) use the term shared, driverless vehicles and in addition, Greenblatt and Saxena (2015) refer to the same concept as autonomous taxis. This lack of a common definition demonstrates that researchers are approaching this idea from different angels. However, they all refer to the same concept: the sharing of autonomous vehicles, which can be applied as personal transportation in urban areas. This indicates that autonomous vehicles will make the distinction between carsharing and ride-sourcing obsolete in the future and that the services will be combined and solely referred to as mobility on-demand. This thesis, therefore, refers to the concept as autonomous mobility on-demand (AMOD).

The idea of implementing AMOD has also received attention from companies outside the research sector. Companies like Google and Uber are very much in favour of the concept as they hope to develop a new business model with it. Uber, for instance, is searching for ways to save costs. At the moment Uber is sharing the money a customer pays for a ride with the driver. If in the future all Uber cars were autonomous vehicles, there would be no driver and "the cost of taking an Uber anywhere becomes cheaper than owning a vehicle" (Harris 2015).

Up to date, the focus of the sparse research has been on the implementation of autonomous mobility on-demand in an urban environment. The focus makes sense as urban population and vehicle traffic is increasing and urban transportation is under a lot of pressure to manage the travel demand. But this focus also restricts the concept to one area and reduces the impacts it could have on personal transportation. This thesis aims to fill this lack of research and investigates the feasibility of implementing autonomous vehicles in a rural environment.

4. Mobility Needs in Lower Austria

In 2008, Herry Consult GmbH for the second time in row conducted a survey about the mobility behaviour in Lower Austria[10]. The survey was commissioned by the federal government of Lower Austria, with the aim to identify the use, and reason of use of different means of transportation of the people living in Lower Austria. In total 9,300 people took part in the survey. The format of the survey was a combination of written (by mail) and oral surveys (by phone). The findings are used to assist the federal government in managing and planning their transportation infrastructure.

As this study is the only comprehensive and most accurate survey conducted in the field of mobility in Lower Austria at the time of writing, this thesis analyses this survey to identify the mobility needs of the people of Lower Austria, which can be combined with autonomous vehicles. The aim of the analysis is to identify different mobility patterns and needs that can be satisfied with an autonomous mobility on-demand services. The focus of the analysis is therefore on personal and individual mobility, in particular on automobile travel.

To identify the mobility patterns and needs this thesis first investigated the purpose of travel in Lower Austria, which means of transportation the people use for the different travel purposes, when they travel and who travels. Some of the findings are also compared with data from two other sources: "Mobilität in NÖ. Ergebnisse der landesweiten Mobilitätsbefragung 2003" conducted by Herry Consult GmbH, commissioned by the federal government of Lower Austria; "Mobilität im Alter" conducted by the BMVIT in 2013.

[10] The previous study was conducted in 2003.

There are some limitations to the analysis. As the analysis is based solely on the data produced by the survey conducted by Herry Consult GmbH (2009), no deeper analysis of specific points of interest is possible. Therefore, the collection of new data would be necessary. This was not within the scope of this thesis. The key findings of the analysis are discussed in the subsequent chapters.

4.1. Personal Transport in Lower Austria

Lower Austria, located in the northeast of Austria is geographically the largest of nine federal states in Austria. With 1.6 million inhabitants it is also the second largest state in population (Amt der NÖ Landesregierung 2014). On weekdays, the population of Lower Austria make an average of 2.9 trips per person[11] and travel an average of 1.5 hours (Herry Consult GmbH 2009). In sum, the people of Lower Austria generate over 4.6 million person-trips each workday.

Due to the size of Lower Austria and the high number of daily trips, the state has built up a comprehensive traffic network in order to secure its attractiveness for people and industry. At present, the state of Lower Austria has a good traffic infrastructure. It has the longest road network in Austria with 31,108 km of roads, as well as the longest railway network, with 1,791 km (BMVIT 2011). Especially, in terms of public transport, Lower Austria offers a good infrastructure. As found by Herry Consult GmbH (2009), 9 out of 10 households in Lower Austria are in walking distance of a bus stop (7 minutes walk) and two third are in walking distance to a train station (16 minutes walk).

However, despite the comprehensive transportation network Lower Austria has built, it still faces a number of challenges. These challenges are mainly connected to the rural character of Lower Austria. Only 30 % of the population live in cities with more than 10,000 inhabitants (Amt der NÖ Landesregierung 2014). The remaining 70 % live therefore in rural areas. Rural areas are in particular characterised by their low population density[12] (Barthelemy and Vidal N.A). The EU distinguishes between densely, intermediate and thinly populated areas (Dijkstra and Poelman 2014). According to their newest classification Lower Austria has areas in all three categories, with three out of five areas classified as predominantly rural[13]. Other characteristics of rural areas are lower income and the dominance of agriculture in the area. In Lower

[11] This number includes non-mobile people.
[12] Lower Austria has a population density of 85 people per square kilometre.
[13] Lower Austria South is classified as intermediate region; St. Pölten, Wald- and Weinviertel are classified as predominetly rural and Wien-Umland is classified as predominantly urban region (Dijkstra and Poelman 2014).

Austria, the average income is 2,014 EUR per month and therefore slightly below the average income in Austria (Koderhold 2015). Furthermore, 48 % of the land is used for agriculture (Amt der NÖ Landesregierung 2014)

The challenges Lower Austria faces in regards to mobility are twofold. On the one hand, the sparse population and disperse settlement structure lead to longer travel distances (Amt der NÖ Landesregierung 2012). On the other hand, although the demand for mobility is high, the sparse population leads to a small demand of public transportation for specific areas and times of day (Amt der NÖ Landesregierung 2012). This makes it difficult for public transportation providers to offer travel services to all regions and at reasonable prices. Therefore, some providers have chosen to schedule their services according to school hours (Amt der NÖ Landesregierung 2012), resulting in limited accessibility and suitability of these services to fulfil the everyday mobility demands of the people. People are, therefore, dependant on automobile travel for their mobility.

The dominant use of automotive vehicles is also an important finding from the analysis of the mobility survey conducted by Herry Consult GmbH (2009). Figure 4 presents an overview of travel purposes and the means of transportation chosen per purpose. It shows that, although the means of transportation people choose depends very much on the purpose of their travel, the car is by far the most important means of transportation in Lower Austria. In six out of seven possible purposes, the people of Lower Austria use the car. Especially for business trips, for pick-up and drop-off, and for work the car has a high importance. The only exception to the dominance of cars is in the case of education. To get to and from a place of education people mainly use public transport.

The importance of automobile travel is also underlined by the number of driving licence holders in Lower Austria. 87 % of all people older than 18 years are holders of a driving licence (Herry Consult GmbH 2009). 95 % of these people also have a car available to them most of the time (Herry Consult GmbH 2009).

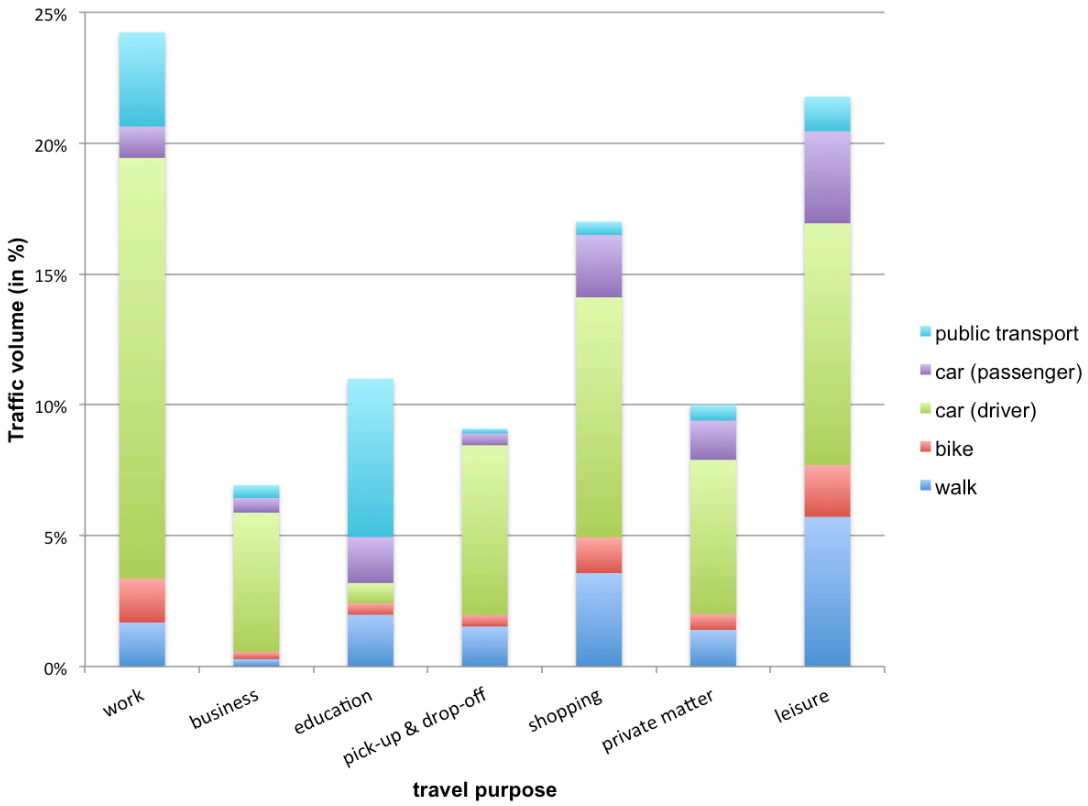

Figure 4: Use of means of transportation based on their travel purposes in 2008

This finding correlates with the increasing car ownership in Lower Austria. Herry Consult GmbH (2009) found a 4 % increase in car ownership from 2001 to 2007. In 2008, 49 % of households had one car and nearly the same amount of households (46 %) had two or more cars. Compared to 2003, this shows two key trends. First, more households have more than one car. Second, fewer households are carless households. A possible explanation for this development is the increasing number of people living alone in Lower Austria. One third of all people in Lower Austria live in a single household (Herry Consult GmbH 2009). But also the number of two-person households is increasing. Therefore every household has, on average, 1.5 cars. If this trend continues, Lower Austria will see 31.6 % more cars on their roads in 2050 than today. This will put a lot of pressure on Lower Austria's transportation system, increasing GHG emissions, oil dependency, safety and congestion.

It is worth noting that the analysis of the survey also shows that the majority of car trips have a vehicle occupation of 1.2 people on weekdays. This number is very low. It is below the average vehicle occupation found by Alessandrini et al. (2015), which was discussed in chapter 2.1 of this thesis. This low number of vehicle occupation in Lower Austria is also highlighted by the low number of people travelling as car passengers. Only 11 % of trips are done as passenger in a car (Herry Consult GmbH 2009). People share a ride for the purpose of leisure activities, to go shopping and for the purpose of education, as illustrated in figure 4. This low vehicle occupation is very uneconomic. Furthermore, it increases vehicle traffic and GHG emissions per person. Consequently, there is a great potential for improvement. Increasing the number of passengers travelling in a vehicle will therefore be crucial for Lower Austria to make personal mobility more sustainable.

Moreover, the survey found that the majority of trips are short trips. The average length of a trip is 14.7 km. In regards to car travel, these have an average length of 15.7 km. Moreover, 75 % of all car trips are shorter than 20 km (as shown in figure 5) and 65 % of all trips end after a maximum of 20 minutes (Herry Consult GmbH 2009). At the weekend the travel distance is even shorter. The majority of trips (69 %) end before reaching a distance of 10 km and only 15 % are longer than 20 km (Herry Consult GmbH 2009). Compared to 2003, the analysis also found that the distance of car travel is getting shorter and that longer distances are increasingly done by public transport.

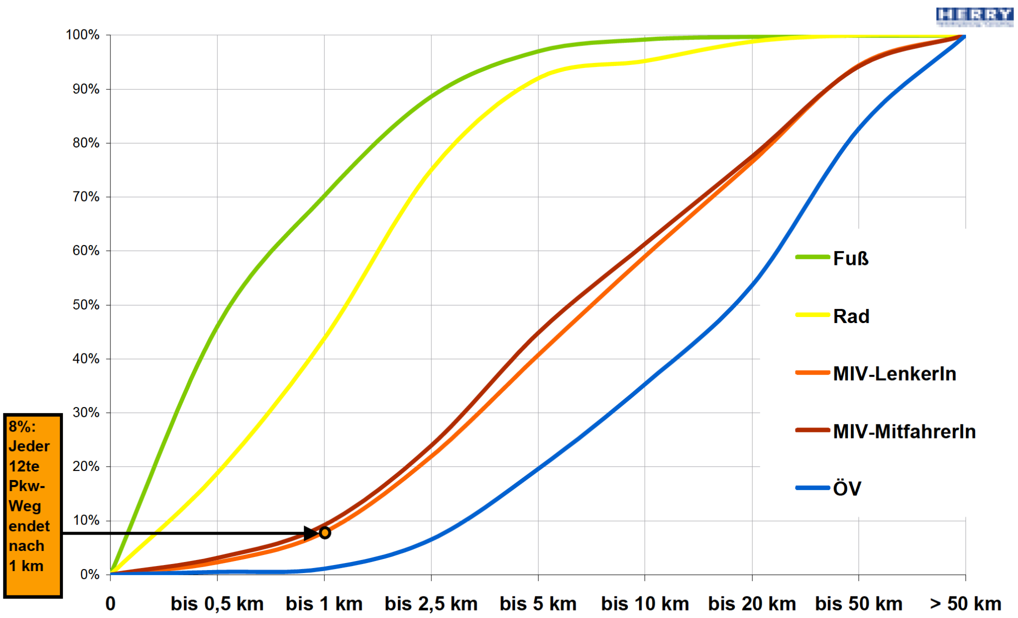

Figure 5: Frequency of travel distances on weekdays in 2008 (in %) (Herry Consult GmbH 2009)

4.2. Mobility Needs based on Travel Demand

The mobility of people is connected to the accomplishment of a certain task or activity. To understand the mobility needs of people it is, therefore, important to first understand why people travel. As shown in figure 6 the people in Lower Austria travel for a number of reasons. The first reason for travel is leisure-related activities. These activities included leisure activities, shopping, private matters and pick-up and drop-off, and constitutes more than half of all travel (58 %). Travelling to and from work represents with 24 % a significant amount of travel. Together with business trips and the travel to and from school, all work-related travel accounts for 42 %, making it the second most common purpose of travel. These two main reasons for travel will be discussed in more detail in the following subchapters.

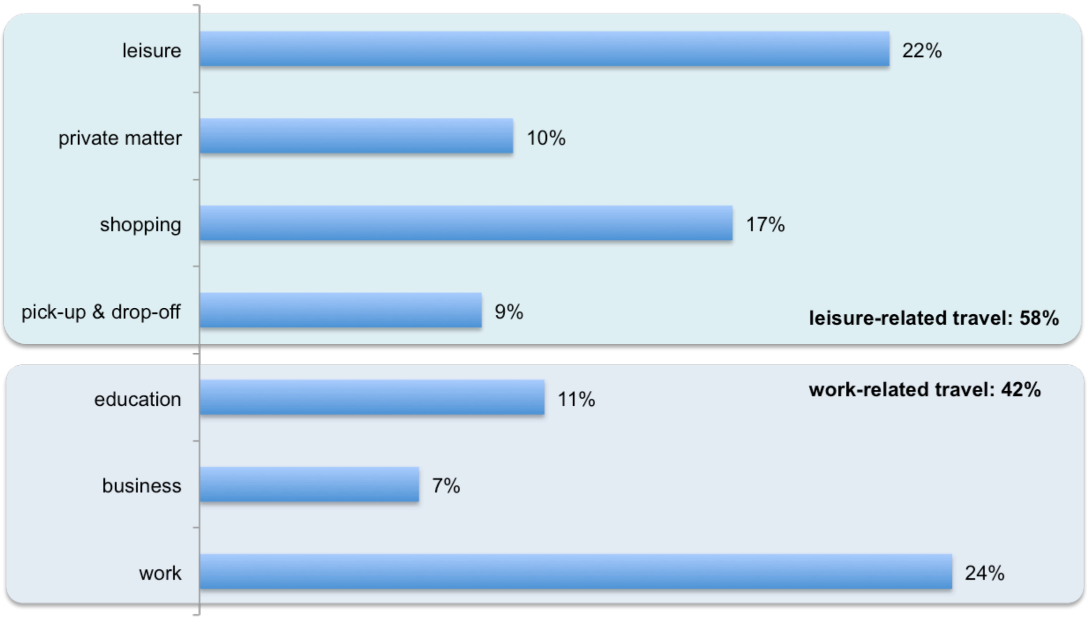

Figure 6: Travel purposes of Lower Austrians on work days in 2008

4.2.1. Work-related Travel

As illustrated in figure 6, work-related travel includes travel to and from work, business trips and the travel to and from school. Travel to and from work accounts for 24 % of travel in Lower Austria and is therefore the biggest contributor to traffic. The average travel distance of these trips is 20.9 km, with an average travel time of 30 minutes (Herry Consult GmbH 2009). For Lower Austria this is very typical. The majority of people do not live close to their work place and therefore have to commute. This is the case for 75 % of inhabitants in Lower Austria (Kronister 2015). Their work place is located in a different district than their home district. Of these, 85.9 % commute to Vienna for work (Kronister 2015), in terms of population this means every forth inhabitant of Lower Austria works in Vienna (26.3 %).

As shown in figure 4, cars are used to a large extent to commute to work. Commuting to work by car causes a lot of traffic and is very uneconomical. The car is used only for a short amount of time twice per day and mainly at peak hours. In the case of Lower Austria, the cars used to commute to work are used on average one hour and then they are idle for the rest of the day. This results in cars standing more than they are being used.

The further away the workplace is located from the people's home address, the more likely it is that public means of transportation are used for commuting. This is also shown in figure 4 that indicates that 27 % use public transportation to commute to work (Herry Consult GmbH 2009). However, 52 % of these people also use the car to get to public transport (Herry Consult GmbH 2009), and therefore use park & ride facilities for example at train station. Park & ride facilities have been introduced to make public transport more accessible and to decrease vehicle traffic and emissions. This measure may have helped decrease traffic on highways by shifting it to rail services, but it also has some downsides.

First, to accommodate the vehicles at train station, the government of Lower Austria has built 188 park & ride facilities in total (source). They provide parking for 11 % of the commuting population using public transport and the car. However, 14 % would be needed to satisfy the entire demand. The demand for park & ride is also expected to increase. Herry Consult GmbH (2009) found that the travel distance to work and education is increasing. As noted above, the larger the travel distance to work the more people use public transport to commute to work. If this trend increases the government will have to build more park & ride facilities, which cost a lot of money.

Secondly, the increased use of park & ride facilities is putting additional pressure on Lower Austria's transportation network. Not only does it increase the need for park&ride facilities in many communities in Lower Austria, it also increases vehicle traffic around the facilities, especially at peak hours. Moreover, similar to cars used to commute to work, the vehicles remain idle and unused, while the people continue their journey to work on public transport. This is again very uneconomical and involves a lot of unused capital.

Figure 4 further indicates that the vehicle occupation is very low when people travel to work, to school or for business with their car. This finding is illustrated by low percentage of people travelling as car passenger in these three travel purpose categories. This behaviour is again very uneconomical and bad for the carbon footprint of the road traffic sector. It is therefore important that this individual transport nature is transformed into more shared rides.

4.2.2. Leisure-related Travel

Leisure-related travel accounts for the majority of trips in Lower Austria. 58 % of all travel in Lower Austria is done by people in their free time. Compared to the previous mobility study conducted in 2003, leisure-related travel has seen the most significant increase. The increasing leisure-related travel is due to more leisure activities. Leisure activities account for 22 % of travel (see figure 6). In the survey, 37 % indicated that they travel in their free time to meet friends and 17 % to do sport (Herry Consult GmbH 2009). On the other hand, higher life expectancy in Lower Austria, a longer period of education and more pick-up and drop-off related travel is also increasing leisure-related travel (Herry Consult GmbH 2009). This shows that leisure activities are gaining in importance and reflect a change in people's lifestyle.

Similar to work-related travel, the majority of leisure trips are done by car. No matter if the purpose is shopping, a private matter, pick-up and drop-off or a pure leisure activity, in 42 % to 72 % of the cases the car is chosen. This makes the car the most important means of transportation.

The car is especially important to allow car drivers to pick up and drop off other people. In 72 % of trips for this purpose are done by car (Herry Consult GmbH 2009). Pick-up and drop-off travel is a notable travel purpose. On the one hand it causes traffic, but more importantly it is time consuming. The average travel time of pick-up and drop-off trips is 14 min (Herry Consult GmbH 2009). Compared to the amount of travel caused by business travel and education travel it is in the same category and therefore should be treated with the same importance. Reducing the amount of pick-up and drop-off travel will be important to let people use their time more efficiently.

The second most used means of transportation in leisure-related travel is walking. Walking accounts for approximately 20 % of leisure-related travel and is done especially to get to leisure activities as well as to go shopping. This is very different to work-related travel, where the second most used means of transportation is public transport. This indicates that shopping and leisure facilities are located close to residential areas and therefore better accessible than places of education and employment.

It is also worth noting, that the importance of leisure-related travel increases on weekends. As a significant amount of Lower Austrians do not work on weekends, leisure-related travel is by far the most significant purpose of travel. Travel to leisure activities account for two thirds of travel (Herry Consult GmbH 2009), making it the most important reason for travel. All leisure-related travel sums up to 90 % of travel

(Herry Consult GmbH 2009). Although the car is used for most trips on weekends, the amount of trips taken by car does decrease from 53 % to 41 % (Herry Consult GmbH 2009). A similar development is noted with public transport. In contrast walking increases as well as the travel as car passenger. The increased travel as car passenger is reflected in vehicle occupation, which is at 1.6 people per car on weekends.

Herry Consult GmbH (2009) predicts that leisure-related travel will further increase in the future. This will have a significant effect on vehicle traffic and decreasing this traffic or shifting it to other means of transportation should be the focus of future mobility models.

4.3. Mobility Demand in the Course of the Day

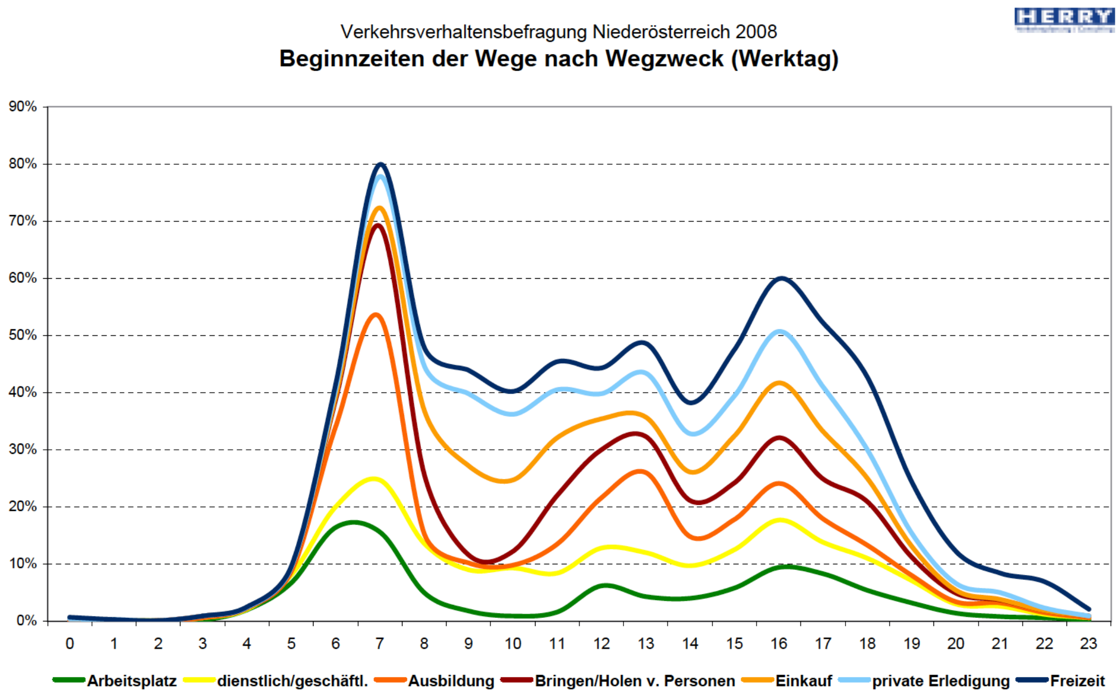

Figure 7: Starting point of trips based on their purpose in the course of a day (week days, 2008, in %) (Herry Consult GmbH 2009)

Herry Consult GmbH (2009) also characterises trips by their purpose and starting time. This data is displayed in the graph below (figure 7) and is especially valuable as it indicates when travel demand is high and transportation should be available. Figure 7 shows that the traffic peaks in Lower Austria are between 7:00 and 16:00 on workdays and are more or less constant in between. (On weekends these peaks shift to 10:00 and 15:00 (Herry Consult GmbH 2009).)

For the purpose of this thesis, only the trips taken by car are analysed. As figure 7 does not distinguish between the different means of transportation, the automobile travel has to be extracted from the data. To obtain these numbers I multiplied the percentage of trips per hour and purpose with the percentage of trips that are typically taken by car for the respective purpose. In chapter 4.2 of this thesis it was found that a certain proportion of people who travel to work by public transport also use the car and therefore use park & ride facilities. This is also the case for a proportion of people travelling to their place of education by public transport. As this traffic is also automotive traffic, I have added these numbers to the work and education travel. The results are displayed in figure 8. Different to Herry Consult GmbH (2009) I have chosen to display the results as separate values and not accumulative, as in figure 7.

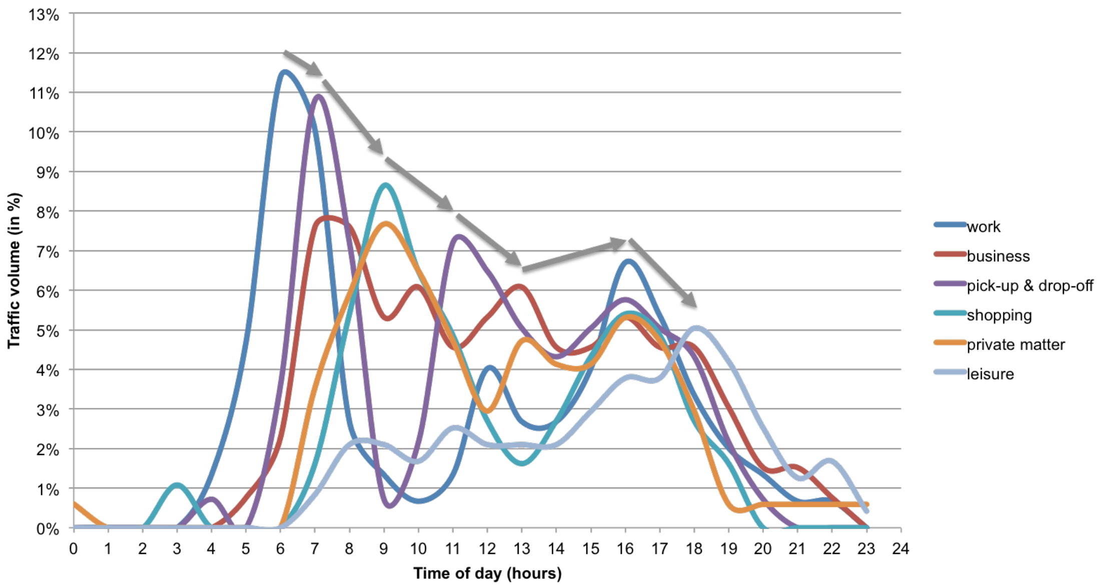

Figure 8: Starting point of automobile trips according to their purpose (on weekdays, including park & ride, in %)

In regards to peak travel demand, figure 8 shows a similar picture as figure 7. The traffic peaks are in both cases at 7:00 and 16:00. However, as figure 8 focuses solely on automobile travel the first traffic peak already begins at 6:00. This is due to the high work-related traffic at this time of day, which is manly car traffic. In addition, figure 7 indicated that in the morning travel starts depending on the purpose at different times, but in the afternoon a significant amount of travel is concentrated around 16:00. Consequently, the analysis of the car travels per hour and purpose underlines two important findings: first, the dominant use of cars for different travel purposes; second, car travel has different peaks throughout the day, depending on their purpose. For example, shopping- and private matter- related travel starts at 9:00, whereas pick up/drop off- related travel starts at 7:00 and at 11:00.

Furthermore, figure 8 indicates that trips with different travel purposes can be connected and therefore done with one car instead of many. As the arrows in figure 8 demonstrate, in the morning it is possible that a vehicle takes a person to work, at 6:00, and then at 7:00 continues to pick up children and take them to school. At 9:00 the same vehicle can pick up a person and drive him or her to a supermarket for shopping or to the doctors or a local authority for private matters. Between 11:00 and 13:00 the car can continue and pick up people, for example children from school and drive them home. At 16:00 there is high demand for the vehicle as people have various travel demands at this time. After settling this demand, the vehicle can continue and drive a person to a restaurant to meet friends, to a sports facility or any other leisure facility they desire.

The findings, therefore, demonstrate that work, pick-up and drop-off, shopping and private matter can be combined and done by one vehicle. As the average car travel is short (average of 15.7 km and 21 min), it is also possible that one car does not only chauffeur one person per hour, but more. However, the exact number cannot be determined from this analysis and requires further research.

I also want to point out that although automobile travel demand is less at 16:00 than in the morning at 7:00, people travel for a bigger variety of reasons at 16:00. This means that vehicle traffic also has a variety of different start and end points and that it is not concentrated on specific routes. For a mobility service based on AMOD this means that the fleet has to be well distributed in the afternoon, whereas in the morning it can be concentrated in residential areas.

4.4. Mobility Demand based on Age Groups

When analysing mobility needs it is also essential to analyse who uses which means of transportation. As shown in figure 9, age strongly influences the choice of transportation. It is therefore crucial for planners to know which age group uses which transportation in order to provide the appropriate infrastructure and to ensure the satisfaction of mobility needs of all people.

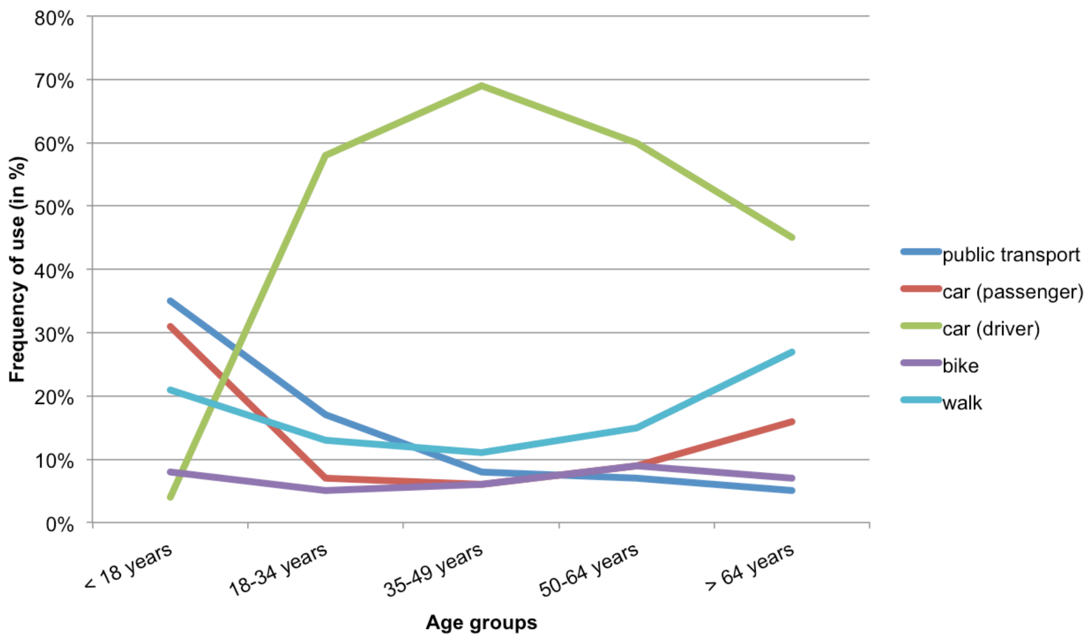

Figure 9: Use of means of transportation based on age groups (in %)

Figure 9 illustrates that adults are a homogenous group in their choice of transportation – they dominantly use cars. The people in this age group are also the most mobile people. They make approximately 3.4 trips per mobile person and due to their predominate use of cars are mostly responsible for high vehicle traffic. In comparison, young people and elderly people are rather inhomogeneous in their use of transportation. For this reason, their choice of transportation will be analysed and discussed in more detail in the subsequent chapters.

4.4.1. Elderly People

The share of people older than 65 years is growing in Lower Austria and predicted to reach a share of one third of the population (30 %) by 2050 (Statistik Austria 2015). This is an increase of more than 10 % as in 2014, people older than 65 years accounted for only 19.6 % of the population (Statistik Austria 2015). Enabling the mobility of this age group is therefore a key task for all traffic planners and will be crucial for society to ensure that people enjoy self-determined mobility for a long time.

The impact of this growing group of people on transportation is already felt today. Due to higher life expectancy and better physical and mental health, people older than 65 years are still capable of driving and are increasing the number of driving licence holders. This consequently affects the number of car holders and is increasing vehicle traffic. This can also be seen in figure 9, which shows that cars are the predominant means of transportation, even in the age group of 65+ years.

Although the age group 65+ years tends to travel less and shorter distances, the increased use of automobile travel in this age group has led to an increased automobile travel. Compared to 2003 automobile travel is replacing walking as well as the use of public transportation. Together with the trend of increasing car ownership (discussed in chapter 4.1), this trend is putting pressure on Lower Austria's transportation system, and increasing GHG emissions, oil dependency, safety and congestion. Future mobility models should therefore especially consider the mobility needs and behaviour of this age group.

To allow a more in-depth analysis of the mobility needs of people in this age group, I have also included data from a mobility study conducted by BMVIT (2013). BMVIT (2013) investigated the mobility behaviour of the aging society in Austria and found that elderly people do not only favour cars for travel, but also have a "fixation" on cars. The study states that for elderly people it is difficult to change their pattern of behaviour and therefore give up driving. Moreover, BMVIT (2013) reports that elderly people are increasingly dependent on their car, as they tend to live in less central areas and public transportation is less accessible to them. These findings indicate that automobile travel will further increase due to the aging society.

The second most used means of transportation in this age group is walking. 17 % of travel is done by foot in this age group. This makes people older than 65 years the largest group settling their mobility needs by foot. The dominance of walking as means of transportation was also found by the BMVIT (2013). According to both studies ((BMVIT 2013) and (Herry Consult GmbH 2009)) the reason for the increased travel by foot and the decreased travel by other means of transportation is the reduced mobility of elderly people. Herry Consult GmbH (2009) found that 25 % of Lower Austrians aged over 65 years have reduced mobility and BMVIT (2013) highlights that reduced mobility increases with age. These people are, therefore, reliant on others to drive them – 16 % travel as car passengers – and on accessible transportation. Accessible transportation will become a necessity in the future and in the case of Lower Austria a lot has to be done. This is indicated by the low use of public transport by elderly people. Only 5 % of trips are done by public means.

Next to the means of transportation, also the purpose of travel changes with age. As elderly people do not have to work anymore, their main purposes of travel are shopping (42 %), leisure (38 %) and private matters (12 %) (BMVIT 2013). This need should also be addressed by traffic planners.

AMOD can help ensure the self-determined mobility of people aged over 65 years of age. By offering door-to-door trips this mobility model can solve the first and last mile problem especially elderly people face with public transportation and eliminate the need for example family members to chauffeur them to a desired destination. Moreover, share autonomous vehicles can make it easier for elderly people to give up their driving licence and driving, but without reducing their mobility.

4.4.2. Young People

Similar to elderly people, young people (aged 13 to 26 years) have a high demand for mobility, but are restricted in their access to cars and therefore use a variety of means of transportation. With 39 %, public transportation is their main means of transportation. As 62 % of young people go to school[14], it is no surprise that their main reason for travel is education. This high travel demand is also the reason why public transportation is the main means of transportation in regards to education.

However, young people are also the second largest group travelling as passengers in cars. This amount of travel is again linked to education. As shown in figure 9 car passenger travel accounts for 16 % of education-related travel. This indicates that parents drive their children to school.

As second most popular means of transportation for young people is to walk. Together with the age group 65+ years, this age group accounts for the majority of travel done by foot.

Although young people use a lot of public transportation, the analysis also indicated that young people have a high affinity for automobile travel. In Lower Austria, young people are allowed to get a driving licence at the age of 18, and in special cases also at the age of 17. Therefore, the percentage of licence holders between 17 and 21 year olds is 72 % and increases to 90 % for 22 to 26 year olds. This trend is underlined by the rapid decline of public transport usage in the same age groups. Whereas at the age of 13 to 16 years 49 % use public transport, only 38 % of 17 to 21 year olds use public transport and at the age of 22 to 26 years this number falls to a low of 25 %. These

[14] This is the mean value for 13 to 26 year olds. For 13 to 16 year olds 100 % go to school, for 17 to 21 year olds 65 % go to school and for 22 to 26 year olds 33 % go to school (Herry Consult GmbH 2009).

findings are very significant. They very much contradict the findings of other youth studies that found that the status of cars is fading within the younger age groups.

The high affinity for automobile travel in Lower Austria is therefore an essential finding, as young people are the traffic participants of the future. The findings indicate that a change of mobility behaviour has to happen at a young age and that alternative mobility models should be installed soon to allow a transition to a sustainable transport system in the next two decades. The next chapter, therefore, moves on to discuss the mobility needs of people living in rural areas.

4.5. Mobility in Rural Areas

To assess the mobility behaviour of the population in different regions in Lower Austria, Herry Consult GmbH (2009) conducted additional surveys in four pre-selected regions. These areas are Southern Mostviertel, Tullnerfeld West, selected parts of the Waldviertel, and Melk (city). An exact list of the areas included in the four regions can be found in appendix 2. The areas are also illustrated in figure 10. The data obtained from these surveys was analysed in this thesis and the results are discussed in this section. Although Melk is considered a city in Austria, it only has approximately 5,300 inhabitants and it is not one of the few Lower Austria cities above 10,000 inhabitants. In this thesis it is therefore considered as semi-rural and therefore included in the analysis.

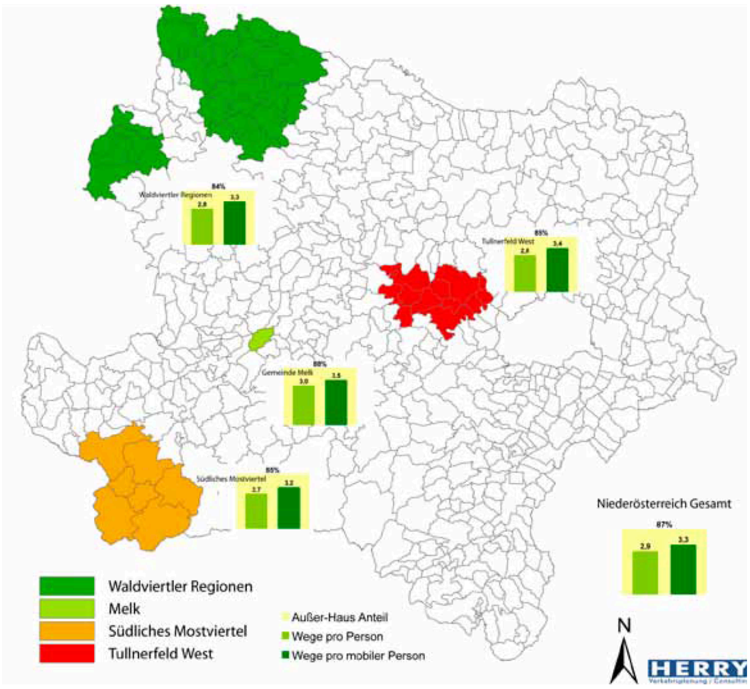

Figure 10: Map of Lower Austria illustrating the four additional surveys regions (Herry Consult GmbH 2009)

Compared to the overall results found for Lower Austria, the four rural areas present similar percentages of driving licence holders (Lower Austria: 87 %, Waldviertel: 85 %, Tullnerfeld West: 89 %, Melk: 84 %, Southern Mostviertel: 87 %). This is also the case for cars per household, where Lower Austria has an average of 1.5 cars per household. In comparison, Melk has slightly less (with 1.4 cars per household) and the other regions slightly more with all three claiming 1.6 cars per households.

In regards to means of transportation, the rural areas present a light deviation from the average Lower Austria numbers. Figure 11 compares the results of the four rural areas with the results presented in chapters 4.1 to 4.4 for Lower Austria in total. The results for Lower Austria in total are treated as mean value and only the deviation from the mean value is illustrated in figure 11.

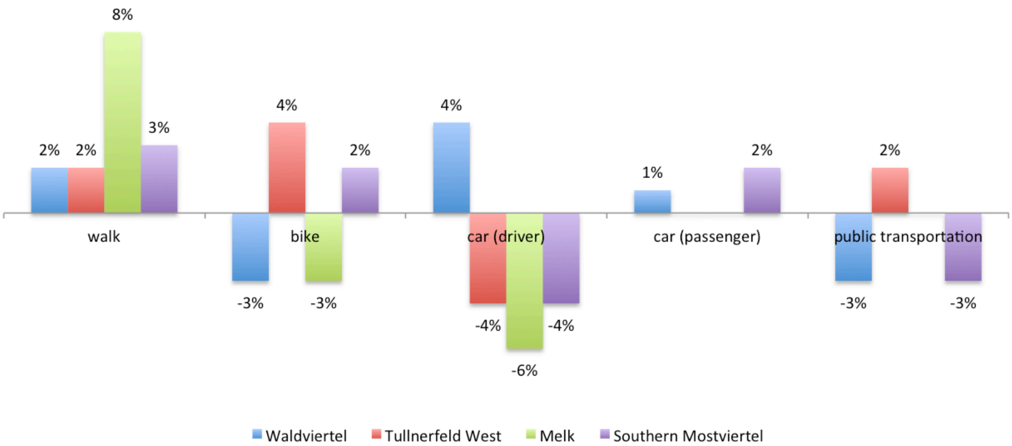

Figure 11: Comparison of the use of means of transportation in regions in Lower Austria

The comparison shows that there is an occasional correlation between areas with the same population density. For example, Waldviertel and the Southern Mostviertel have very similar population density of 32 to 34 people per square kilometre and show similar proportions of travel by foot, car passenger and public transport. Compared to the overall results for Lower Austria, public transportation is the only means of transportation used less in both regions (-3 %). A reason for this can be the decreased accessibility of train stations. This underlines that sparsely populated regions are difficult to provide with affordable and economical public transportation and therefore lack this form of mobility.

In regards to car (driver) travel the Southern Mostviertel shows below average travel, but therefore increased travel by bike and walking. This finding can be explained by the high number of elderly people living in this area (source). They tend to travel shorter distances for which they can take the bike or walk and which results in less car traffic for the overall region. In comparison, the Waldviertel shows increased car travel and walk. This is also related to the decreased accessibility of public transport in this area. To reach public transportation people have to take their car or choose to travel solely by car instead of switching to public transportation. The decreased travel by bike suggests that the area is lacking adequate infrastructure for this means of transportation.

The city of Melk and the region Tullnerfeld West are both more populated areas. Melk has a population density of 206 people per square kilometre and Tullnerfeld West has 135 people per square kilometre. The mobility behaviour of the people living in Melk is significantly different than in other areas and indicates that the people enjoy a good infrastructure in their proximity. Instead of taking the car, the people of Melk ride their bike and walk. The region of Tullnerfeld West also has managed to offer an alternative to driving. Instead of taking the car, the people prefer to use public transportation and ride the bike as shown in figure 11. This shows that if alternatives are provided, people do decrease the use of cars.

Despite the deviations from the mean value, automobile travel is in all areas the dominant means of transportation. The more rural it gets the more the car is used and the less public transportation. Also slightly more people travel as car passenger. Compared to the overall results for Lower Austria, walking is done significantly more often and therefore constitutes an important means of transportation in rural areas.

Next to the means of transportation, also the travel purpose was analysed for the four selected areas. As in the previous analysis the overall results of Lower Austria are taken as mean value and compared to the four rural areas. This comparison is provided in figure 12. The results of the analysis present little deviation from the overall results found for Lower Austria.

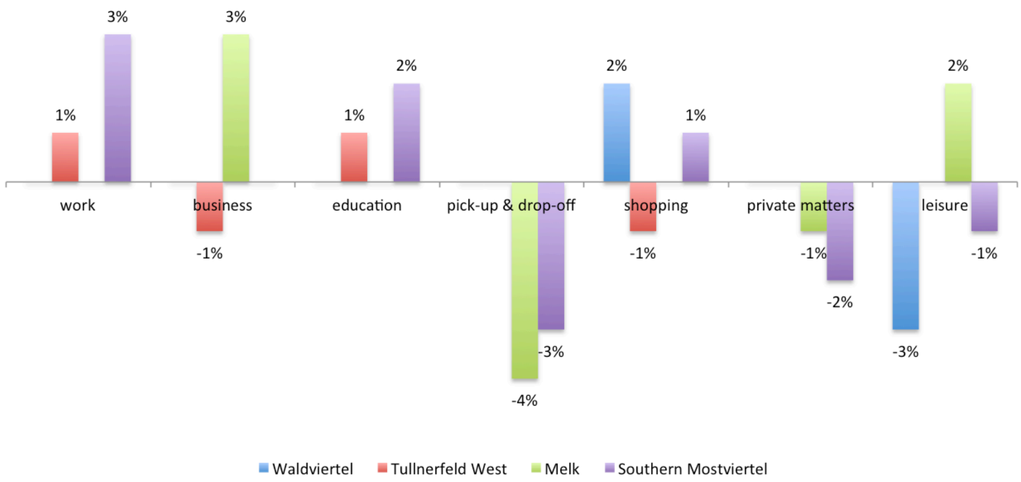

Figure 12: Comparison of the travel purposes in regions in Lower Austria

Figure 12 reveals that the proportion of work-related and leisure-related traffic in all four regions is nearly identical. The only exception is the Southern Mostviertel with slightly more work-related traffic. This is due to the slight increase in trips to and from work and to and from the place of education. As the Southern Mostviertel shows a small increase in education travel, it could be expected that this would also increase pick-up and drop-off travels, as seen in the previous analysis in chapter 4.2. However, the exact opposite is the case. Pick-up and drop-off travel is 3 % less than compared to the overall results for Lower Austria.

Other results are: less leisure travel in Southern Mostviertel and Waldviertel and increased leisure travel in Melk. This indicates that the people in more rural areas spend their free time at home, whereas people in a more urban environment tend to travel to enjoy their free time. In addition, Melk shows below average pick-up and drop-off travel.

The comparison of the purpose of travel and the means of transportation, unfortunately did not find any correlation between the two factors. To gain better insight which types of transportation are used for which purpose in rural areas and how this changes from area to area more data would be needed, and which was not provided by Herry Consult GmbH (2009).

In summary, the results in this chapter indicate that the mobility needs of people in rural areas depend on the transportation infrastructure provided, which is no surprise. In addition, the low deviation from the mean value suggests that the results of Lower Austria in total are representative for rural areas.

5. An Autonomous Mobility On-Demand Service for Lower Austria

As noted in chapter 2, autonomous vehicle technology shows a lot of potential to remove the inefficiencies of conventional vehicles. Various market players are therefore pushing for a fast development of these vehicles and automation level 3 may be on our streets by 2020. Although it will take time for autonomous vehicles to achieve a dominant market penetration, the replacement of the human driver by computer algorithms will already help improve safety, congestion and emission production personal mobility. But the biggest improvements will come with the implementation of a new mobility system. As identified in chapter 3, mobility on-demand services are changing the way we use and perceive personal transportation. Combined with autonomous vehicles, they promise to eliminate the limitations of current mobility on-demand models, to address all of the issues associated with personal mobility and to allow the development of a new mobility system also for rural areas.

A research question of this thesis is: “How could a mobility model based on autonomous mobility on-demand (AMOD) that serves the travel demand of Lower Austrians be designed?” To answer this question, this thesis combines the previously described mobility model (AMOD) with the mobility needs identified in chapter 4. This mobility model should be designed in such a way that in the best case the users can give up their private vehicles or one of their private vehicles and switch to this service, whilst experiencing equal mobility.

The identified mobility needs can be summed up in seven points: 1) Lower Austria is a car state. The car is the most important means of transportation for the majority of travel purpose. Due to the rural environment of the state, people are dependent on automobile travel to secure their mobility. 2) This and changes in lifestyle is increasing car ownership in Lower Austria. 3) Vehicle occupation is very low and should be increased. 4) Work travel was identified as the most uneconomic travel, which causes the highest degree of idle cars throughout the day. 5) The majority of automobile trips are short (75% is below 20 km) and a trend shows that they further decreasing in length. 6) The most dominant purpose of travel is leisure. 7) The population is aging and their special needs have to be addressed.

The aim of this chapter is not only to design a new mobility system, but also to evaluate whether the developed model can provide sustainable mobility for people living in rural areas. In order to evaluate and develop such a mobility model the following assumptions are made:

First, all vehicles are electric vehicles. This assumption is based on the findings from chapter 4. These indicate that the majority of trips are short, the average length of car trips is 15.7 km and 60 % of all vehicle trips are shorter than 10 km (see figure 5). This suggests that electric vehicles can make at least 60 % or more trips. Moreover, electric vehicles produce no tailpipe emissions compared to vehicles with internal combustion engines and therefore their use has a positive effect on the environment.

Second, it is not reasonable to assume that the mobility system will be able to provide for all needs at the beginning. Therefore, only the most suitable trips for mobility on-demand are considered. These are automobile trips to work, to school, leisure trips and all leisure-related trips. They have been identified as suitable as on the one hand the use of individual transportation was identified as inefficient in chapter 4 to satisfy this travel demand. And on the other hand these are trips that are taken inter alia by elderly people for whom mobility is especially important. Consequently, business trips are left out. In this case the assumption is made that these trips are made by people travelling throughout the whole working day. Replacing these trips with shared vehicles is therefore difficult and therefore not considered in this model.

Third, the majority of Lower Austrians possess smartphones and therefore have access to smartphone apps and the mobile internet. This assumption is based on the findings of Mobile Communications Report 2015 that concludes that Austria has a smartphone penetration of 86 % and that 82 % of Lower Austrians use the internet on their mobile phone (MindTake 2015). The study also found that 70 % of 60 to 69 year olds in Austria have a smartphone (MindTake 2015), which proves that a smartphone-based service does not expel this age group from this service.

5.1. Description of the Model

In order to get an understanding of how an AMOD system might serve Lower Austria, a basic model of implementation is assumed. This model is based on the findings from chapter 3 and 4. The basic model can be described as follows:

Similar to car2go, fleets of autonomous vehicles are distributed throughout Lower Austria and are coordinated by a smartphone app. By using the app, customers can request a vehicle. Instead of having to walk to the vehicle, like with car2go, the vehicle drives to the customer, picks the person up and drives him or her to their desired destination autonomously. Upon arrival, the passenger does not have to park the vehicle. Instead, he or she gets out of the vehicle and the vehicle can continue on to the next nearby customer requesting a ride.

Access to this service is provided via a smartphone app. People who want to use the mobility service first have to register. The registration process can be organised similar to Uber and car2go. People can register either online or via the app. In order to register they need a credit or debit card, which is used to validate the person. As the vehicles drive autonomously, the users do not need a driving licence to use the service. Therefore, the registration process can skip the validation of the driving documents, which is a necessary step when becoming a car2go customer. Once the user is registered he or she is ready to use the service and to request a vehicle.

To match customers and vehicles, the app uses GPS to locate the client and the closest available vehicles. This vehicle may be idle or in operation. As the system knows the position and the final destination of all its vehicles, the system can calculate which vehicle can arrive at the customer first and when the vehicle will arrive at the customer. This information can also be passed on to the customer via the app, informing him or her about their waiting time. The routing of the customer and vehicle is illustrated in figure 13. By entering the desired destination of the trip, when requesting a vehicle, the customer can also receive a price estimate.

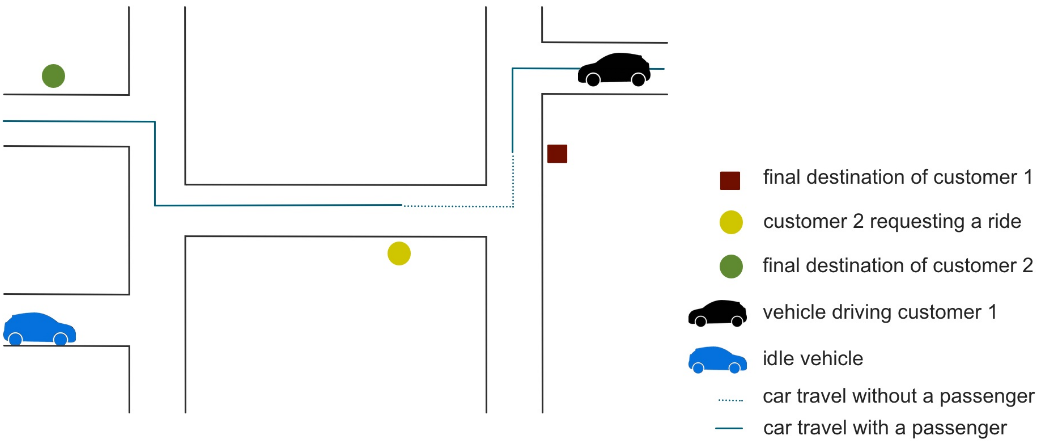

Figure 13: Routing of the customer and vehicles

When the vehicle arrives to pick up the customer, the customer can unlock and enter the car by using his phone. This process can also be adapted from car2go, where the user enters a pin-code to unlock the vehicle. Once in the car, the passenger confirms his desired destination in the app and the vehicle starts the journey. The vehicle drives autonomously to the requested final destination. It chooses the route according to the latest traffic information it received via V2X technology. This allows the vehicle not only to choose the quickest route, but also to avoid traffic congestion. Upon arrival, the final price for the trip is calculated and the passenger can pay directly via the app, as the credit card or debit card details are stored in the app.

Furthermore, it is possible that people walk up to a car and use it. In this case they also use the app. By entering the licence number and their pin-code in the app the vehicle unlocks and can be used by the customer.

5.1.1. Travel Demand

In order to understand how an AMOD system might serve the identified mobility needs of Lower Austrians, it is helpful to visualise how such a system could operate. This is done in figure 14.

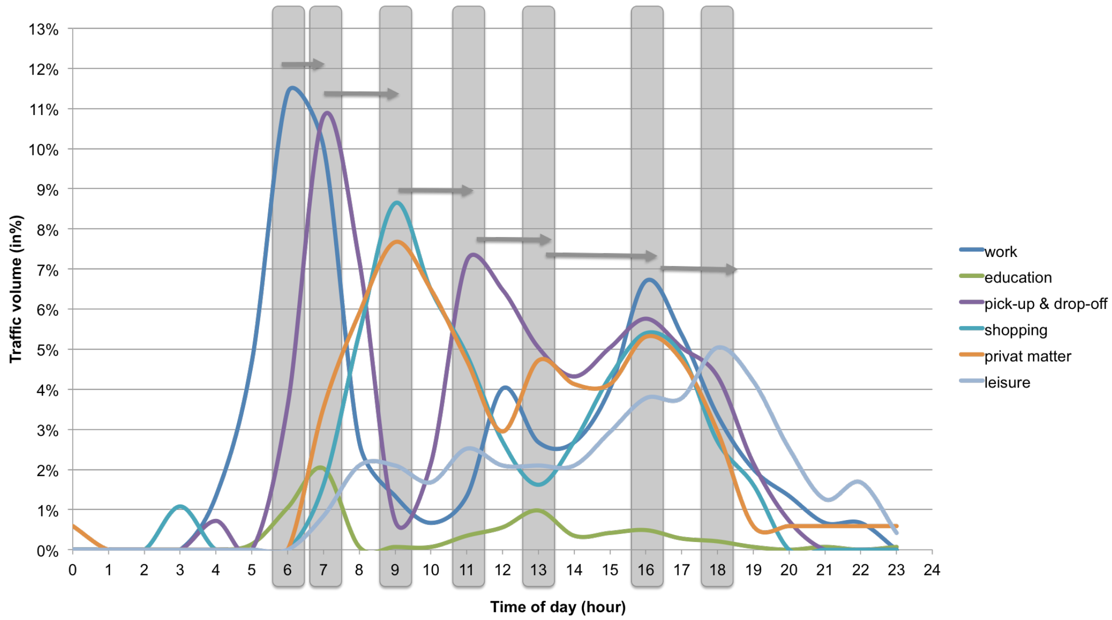

Figure 14: Starting point and peak travel demand of automotive trips according to their purpose (on weekdays)

The findings from chapter 4 provide that people in Lower Austria travel for two basic reasons: work[15] and leisure. As shown in figure 14 travel to work starts in Lower Austria early in the morning and has its peak at 6:00 and 7:00. An average trip to work takes 30 min and is about 20.9 km. Furthermore, the study found that the car is the most used means of transportation to work and 60 % of all trips are shorter than 10 km (see figure 5). This suggests that at least 60 % (and more) trips to work could be made by using shared autonomous vehicles. A shared autonomous vehicle can pick up a person and drive him or her to work or to a train station with the same convenience as if the person were driving his or her private vehicle. Instead of parking the vehicle at the workplace or the train station and leaving it idle for many hours, the autonomous vehicle can continue to the next customer.

This new customer can be another person requesting a ride to work at a later time, or children that need to go to school. As shown in figure 14 pick-up and drop-off travel starts a little bit later than work travel and has its peak at 7:00. As found in the study, travel at this time is related to parents bringing their children to school. Similar to pick-up and drop-off travel, children travelling to school on their own, or being chauffeured to a train station, start their travel mainly between 6:00 and 7:00. To save the parents from having to do these trips (and ultimately saving them time and stress), shared autonomous vehicles can take on this duty. The average length of such trips is 7.1 km, as found in the study and therefore can be done by AMOD. This is also the case

[15] In this case, business trips are excluded from work-related travel.

between 11:00 and 13:00, when school ends and children are on their way home or have to be picked up again.

Leisure-related travel, such as shopping and private matter, starts later than work-related travel as illustrated in figure 14. It has its first peak at 09:00, when a lot of people start their travel to go shopping and to take care of private matters. The average travel distance of such trips are between 7.6 km (shopping) and 11.4 km (private matter)[16]. An autonomous vehicle can settle this travel demand after driving people to work and in-between driving children to school and picking them up again.

To offer the same convenience as when driving with a private car, it should be allowed for passengers to hold the ride when for example going shopping. This could be done by clicking "wait for me" in the app and by entering the time the vehicle should wait and park itself close by. Shortly before the time is up the customer could receive a message asking whether he or she still wants the vehicle to wait or if the vehicle can be released from the hold mode and continue to another customer. Offering AMOD for shopping and private matter trips is essential as these trips are the main reason for travel for old people. Allowing them to do these trips can increase their quality of life and assures that they are not isolated from everyday life.

At 16:00 is the second travel peak of the day and in contrast to the first peak, the travel demand at 16:00 is more diverse. People want to travel home from work, want to go shopping, take care of private matters, some children are travelling home from school, some people are traveling to pick others up or drop the off and leisure travel is increasing. In order to settle this diverse demand with shared autonomous vehicles it will be necessary for the vehicles to distribute themselves to all the different points of interests.

The two travel peaks, in the morning between 6:00 and 7:00 and in the afternoon at 16:00, represent a good opportunity for ridesharing. For example, working parents can share a ride with their children, bring them to school and then continue their trip to the train station or directly to work. Trips to work or to the train stations can also be shared by people that live in the same neighbourhood. These trips can be incentivised by offering discounts if people share a ride. Uber, Lyft and Sidecars already provide this feature and as Lyft has shown, up to 40 % of rides can be saved (see chapter 3.2). In chapter 4 of this thesis it was identified that Lower Austria should foster ride sharing due to its low vehicle occupation. Offering cheaper ride fares if people share a ride

[16] Shopping 16 min, private matter 21 min.

would therefore represent a good opportunity to achieve this goal and to decrease vehicle traffic.

5.1.2. Fleet Distribution

A typical weekday travel pattern of a fleet of shared autonomous vehicles was developed in chapter 4 and discussed again in the preceding subchapter. It is reasonable to assume that this fleet will not always be able to relocate and balance itself according to demand. This balance is however necessary to achieve a successful mobility model, that is able to deliver a significant amount of every day trips.

In order to enable a balanced distribution, it is essential to know the travel demand of the users. Based on the travel pattern developed in chapter 4 it is possible to estimate at what time of the day and in which area a shared autonomous vehicle should be located. This is done by assuming the likely origin and or destination areas of the different travel categories. For example, it is very likely that a trip made by car to work will start at home and either terminate at the workplace or at the train station in a park & ride facility. Similar assumption can be made for car trips to school. For automotive shopping, private matter and leisure travel these assumptions cannot be made so easily. These trips can start at home or for example at the children's school or at a workplace. However, the final destination of these trips can be assigned to areas, as shopping, private matter and leisure facilities, which are in general close to city or town centres.

Consequently, these assumptions lead to the following fleet distribution plan: Between 3:00 and 7:00 in the morning shared autonomous vehicles should be located close to or in residential areas. At 7:00 some vehicles should be available at train stations to bring children to school and adults to work. (They should also be located in the proximity of schools, if parents want to escort their children to class). At 9:00 some vehicles should be back in residential areas to take people shopping. At 10:00 vehicles should also be located in the city centre, as well as close to shopping facilities. From 11:00 to 13:00 shared autonomous vehicles should be back at schools and train stations to drive children and people working part-time home. At 16:00, when the travel demand is most diverse, it is essential that the vehicles are well distributed. This means they are located at train stations, at large work places (e.g.: factories, big companies), in city and town centres, at leisure facilities and others. From 18:00 onwards vehicles should again be available in residential areas, close to leisure and sports facilities, restaurants and bars to settle the last travel demands. These findings are also shown in figure 15.

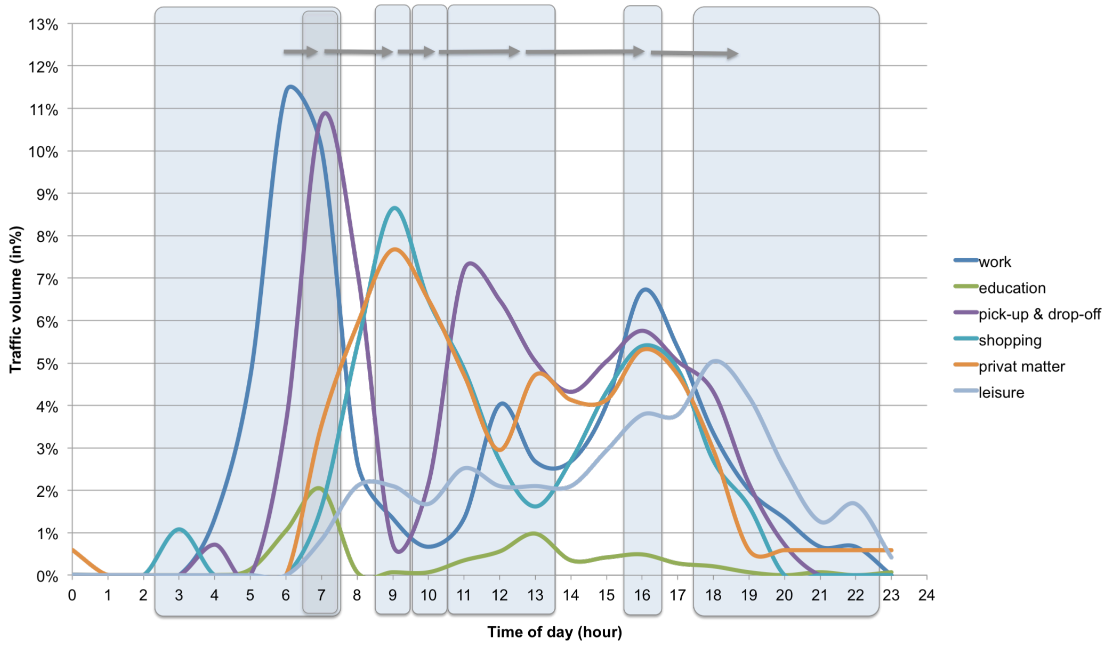

Figure 15: Fleet distribution plan for AMOD on weekdays

This distribution can be reached by two different options. The first option is that the vehicles are distributed according to their use. When a customer requests a shared autonomous vehicle the vehicle closest to the customer drives up to him or her. In this case, it can happen that the closest vehicle has a long access route which leads to long latencies for the customer. The other option is that after each trip the shared autonomous vehicle repositions itself to a location closer to the forecasted future travel demand. This causes additional travel, but if the travel behaviour and demand is well known and forecasted it can result in shorter access routes and ultimately in shorter latencies. Measures that can be applied to better forecast future travel demand is discussed later on in this thesis.

The automobile travel demand in figure 15 also suggests that at night there is time for the vehicles to redistribute and recharge themselves. Recharging will be discussed in chapter 5.1.4.

This distribution will allow the mobility model to best settle the mobility demand of the people of Lower Austria. It is, however, important to highlight, that this distribution plan is based on the mobility needs of the people today and it is likely that with time these will change. Whether this distribution of the fleet of autonomous vehicles is possible without vehicles relocating themselves cannot be clearly said in this thesis. In order to do so more detailed research is necessary.

5.1.3. Fleet and Vehicle Configuration

So far it has only been stated that the fleet of shared autonomous vehicles is comprised of electric vehicles. However, it should also be considered what size and additional features the fleet of autonomous vehicles should possess. As identified in chapter 4, the people living in Lower Austria have different mobility needs during the day and week. These findings suggest that the mobility service should offer different vehicle types.

In regards to vehicle size, this thesis suggests that the fleet should mainly consist of two-passenger cars[17]. As found in the study, the vehicle occupation on weekdays is at 1.2 people per vehicle, meaning that only every fifth trip is done with two people. At weekends the occupation increases to 1.6. Consequently, two-passenger cars should be able to cover the majority of trips. Further advantages are that the two-passenger vehicles are lighter and need less energy and less space for parking. In addition, they need less space on the road and therefore road capacity can be increased.

Alongside these identified mobility needs, it is clear that the vehicles should possess other features. In chapter 4.4.1 of this thesis the mobility needs of elderly people were examined. It was found that these people have reduced mobility, which increases with age and therefore the amount of trips they make per day decreases. To ensure that these people are not isolated in their homes, vehicles that are accessible with wheelchairs, as well as easy to get in and out of should be offered. Furthermore, the study found that a notable percentage of people in all age groups use the car to satisfy their basic shopping needs. Therefore, the vehicles should also offer reasonable storage space.

To complete, it should be considered offering limousines. As discussed in chapter 3.2.2, Uber found that a number of people identify with the vehicle they are driving. As a consequence, Uber offers services that provide rides with limousine and similar automobiles. To settle this desire, the proposed mobility model for Lower Austria should also consider this option.

It will not be possible to combine all these desires in one vehicle. Therefore, the system should consider offering a mixed fleet. On the one hand, this fleet consists of two-passenger autonomous cars, which are distributed throughout Lower Austria for on demand use. On the other hand, the fleet includes special vehicles as discussed above that have to be ordered ahead of time. This will allow the model to fulfil the everyday

[17] Examples for suitable two-passenger vehicles, which have already been discussed in this thesis, are the Google pod (figure 1) and the LUTZ pod (figure 2).

mobility needs of the people, as well as provide mobility for special occasions, like a family trip to the cinema.

How many autonomous vehicles a fleet should compose has to be evaluated in further research. I would, nevertheless,s like to point out that the amount of cars should be according to the demand. Furthermore it should be recognised that it will not be able to provide for all trips at once with the new mobility model. To fulfil as many trips as possible, people will have to change their mobility behaviour and for example share more rides. When people start sharing more rides, the fleet can be adopted and in addition offer five-passenger cars.

5.1.4. Recharging

To allow an optimal flow of the mobility system described in the previous chapters, it is essential to also think about how the shared autonomous vehicles can be recharged once their batteries are depleted. As the mobility system is based on autonomous vehicles that can drive without human intervention, the charging process should be designed to work without human intervention too. This does not only save money for the fleet operators, as they do not have to employ staff to plug in vehicles, it also frees the customer from this duty, provides a more convenient service and enables a predominantly autonomous system. As a result, the charging of the vehicles cannot be done via cable. An alternative solution is necessary.

A possible solution could be inductive wireless charging. Instead of connecting an electrice vehicle via cable with a charging spot, energy is transmitted via induction through a magnetic field. The magnetic field is built up between two coils, a primary and a secondary coil. The primary coil (the source) is buried in the ground and the secondary coil (the receiver) is integrated into the underbody of the vehicle (Borrmann 2014). The coupling medium of the inductive charging system is the electromagnetic field and therefore allows the vehicle to autonomously charge itself, once it has parked itself above the charging spot. A further advantage of the system is that it improves the safety of the charging process as it eliminates cords and cables (Lukic and Pantic 2013).

An additional requirement to enable an autonomous charging system is the integration of the charging stations into the cities and towns of Lower Austria. This suggests that the charging stations should be situated at various points of interests, where a notable number of trips either origin or terminate. These points are for example train stations, shopping areas or city centres. The set-up of inductive wireless charging stations at highly frequented points is referred to in literature as stationary and opportunity charging station (Lukic and Pantic 2013), (Borrmann 2014). Whenever a car battery is close to depletion or the shared vehicle is not immediately dispatched to a new customer, it can drive to such a charging station. At the station it can recharge and remain parked until it is either fully charged again or dispatched to a new trip. This short intermediate charging will allow vehicles to regain energy in-between services and to reassemble close to demand.

A similar system has been implemented in Milton Keys in the UK. Buses can charge at the end of every route, where they stop for 10 minutes before they continue their service (Bowdler 2014). This time is used to recharge the buses and to keep the vehicles gong the whole day. At night, the vehicles are fully recharged. This concept of inductive and integrated charging will be a key element to creating a sustainable autonomous mobility system.

5.1.5. Functionalities of the App

For an AMOD system to successfully work in Lower Austria, the system should not only fulfil the people's mobility needs, but should also be accessible to them as easy as possible. This can be achieved by a smartphone app. The app is therefore a key element of the system design.

As described at the beginning of this chapter, the app provides a number of functionalities. Compared to the car2go app, the services and information offered in this app do not have to be as extensive. Services such as "next charging station" can be received by the vehicle directly via V2I or V2X technology. However, to ensure that the model provides a high degree of mobility to its users and to allow people to switch from private vehicle ownership to a share autonomous vehicle membership, the app will still have to fulfil several additional functions. These functionalities are:

First, it should provide the key to the car. Like car2go, after successfully signing up to this mobility service each customer receives a personal pin code. Whenever they order an autonomous vehicle and it drives up to them, or they walk up to an idle autonomous vehicle they can unlock it by entering their personal pin-code into their smartphone. This offers a high degree of convenience to the mobility operator as well as to the users. The operator does not have to hand out key cards and the customers of the service can use their phone, which most people carry with them all the time and in all situations.

Second, the app can be used as safety feature. How this can be applied successfully has been demonstrated by Uber. Uber allows customers to share their route per text message via their app. This allows the receiver of the text message to follow the person's route and make sure he or she arrives at their destination. A similar function could be integrated into the app of this proposed mobility service. This will allow for example parents to follow the travel of their children when they take an autonomous vehicle to or from school.

Third, the app should assist in planning and distributing the fleet. As identified in the preceding chapters, it is crucial for this mobility service to know its customers travel demand and to tailor the fleet to their needs as well as the changing demand throughout the course of the day. This knowledge can be gained by conducting studies or this thesis and by collecting data about the use of the service once it has been launched. As this bespoke new mobility service for Lower Austria uses an app to make its service available, the app can be used to track all travel. The accumulated data can then be analysed and used for forecasting the demand.

These efforts can further be supported by providing the option to pre-book rides. Instead of allowing customers to only spontaneously request a ride via the app, people can also book rides ahead of time. This way the service can be used on-demand, but also the demand can be better forecasted and satisfied. People, who for example need a ride to the train station at the same time every day on workdays, can pre-book their trips. This ensures that they always get a ride, have short waiting times, and furthermore it helps to forecast the demand. This behaviour can be incentivised by offering price discounts for pre-booked rides. Consequently, the app or to be more specific the mobility service can be described as a learning system. It tracks the mobility pattern of its clients and learns from their travel behaviour.

Finally, to allow a truly sustainable mobility system the app should also integrate other transportation services, such as train, bus and bike. This will allow users of this service to learn which means of transportation are available to them (public and private transportation), what the price of each trip is and how long the travel time will be. If the different mobility services are well integrated, it will also allow people to mix different means of transportation. For example, when travelling home from work, people can check in the app the timetable of the train, buy a ticket for the train and request a shared autonomous vehicle to wait in front of the train station for them upon their arrival at the final destination of their train ride.

A prototype of such an integrated mobility platform has been developed and piloted in Austria from July 2014 to May 2015. The name of the project is “smile – simply mobile”. It was funded by the Climate and Energy Fund of the Austrian Federal Government and included a cooperation of various mobility providers, energy providers, routing companies, park garages and research institutions[18] (smile mobility 2015).

It is important to note, that although this thesis speaks of a smartphone app, it does not consider the app as restricted to smartphones. Mobile technology is quickly evolving and connecting an increasing number of devices with the internet. The app should therefore be understood as app that can be used on tablets, smart watches and any other smart devices already developed or which will be developed in the future.

5.2. Deployment and Implementation

One of the building elements of the new mobility model for Lower Austria are autonomous vehicles and their ability to drive without human intervention and consequently provide a mobility on-demand service also to rural areas. However, it will not be possible to implement this model in all areas of Lower Austria at once. The deployment of the service should be done in steps.

At first the service should be operated similar to car2go. The fleet of the AMOD service is deployed in specific areas and the use of the service is restricted to these “operation areas”. This restriction is in principle against the idea of this thesis, but it is a necessary step. It will allow the people living and working in these areas to adopt the new service and the operator will be able to gain the first insights. For example: what are the specific travel patterns of the people in this area and how well the vehicles balance themselves in distribution. The operator will then be able to adjust the fleet and tailor the service more to the demand of the people.

Once the mobility service has established itself in the first operation areas, the service can be deployed in further areas. Again the implementation will go in phases for the people and the operator to get to know the service. After time, when the service is working well, the operation areas can be enlarged and connected with other areas.

[18] Partners: Wiener Linien, ÖBB, Linz Linien, TwinCity Liner Wien- Bratislava, 31300 (taxi), Citybike Wien, nextbike, Grazbike, car2go, Flinkser, EMIL, emorail, e-Carage, Wipark, Wien Energie Tanke, Energie Steiermark, Parkgaragen Elbl, Verkehrsauskunft Österreich, AIT and toursprung.

This will not only allow the customers of the service to travel further distances and to other regions in Lower Austria, it will also allow the operation areas to work closer together. This cooperation will allow the vehicles to float more freely and enable a joint rebalancing of vehicles as well a joint satisfaction of the travel demand.

To allow not only a free floating of the vehicles, but also to permit the users of the service to use them freely, the system should allow users, once registered, to use the service in all operation areas throughout Lower Austria. Car2go offers this feature to all its clients in Europe. If a person signs up for car2go in one city he or she is authorised to use car2go in any other country across Europe. This increases the convenience of the service and allows greater mobility to its users.

Similar to the app, the implementation of the AMOD system will be a learning process. The users of the service will learn how the services works and how it can satisfy the individual mobility needs. The operators on the other hand will be able to test the setup of their service. They will be able to collect data about the travel demand and patterns of the people, which will let them adjust their algorithms and their offer and scope of service.

This incremental deployment of the mobility model will also allow the operators to gradually provide for more and more trips. Once the service has been well set up and adjusted to the needs of the local population, the system will also understand how to provide for more trips. The vehicles will be able to rebalance themselves more efficiently and the size of the fleet necessary for a region will also be better known. This will also gradually develop, while customers, operators and vehicles learn from each other until finally the AMOD service can provide for a large proportion of everyday trips in Lower Austria.

Another important factor to enable the deployment of this mobility model is the infrastructure. As examined in chapter 2, autonomous vehicles have their greatest impact on safety, efficiency and congestion when they use connected vehicle technology. To allow the use of these technologies the infrastructure of the current traffic system has to be upgraded to an Intelligent Transport System. This means adding wireless technology, sensors, cameras and other communication equipment to the traffic infrastructure. The upgrading of the infrastructure will also include the instalment of charging stations. These are in the best case wireless charging stations, as introduced and discussed earlier on in this thesis.

But other than that, autonomous vehicles will be able to be integrated into the normal traffic. It is possible to allocate specific road lanes to the sole use for autonomous vehicles, but this is likely to be a temporary solution. Different to the PRT pods operating at Heathrow Airport, the autonomous vehicles are being designed to “safely completing journeys […] in all traffic, road and weather conditions” (Department for Transport 2015).

5.2.1. Mobility Operator

So far in this thesis, it has not been discussed who should be responsible for the deployment of this mobility model and consequently the operator of this new mobility service. This will be taken up in this section.

As operator of the AMOD service in Lower Austria there are a number of possibilities. The service could develop similar as mobility on-demand services are developing currently. Car manufacturers such as Mercedes-Benz decide to replace their existing car2go fleets with autonomous vehicles and slowly expend their service in urban as well as in rural areas. On the other hand, start-ups such as Uber can take up this idea, put together a fleet of autonomous vehicles and set up the service. Of course this is also an option for already established taxi companies, who wish to save the costs of the drivers. However, it is also possible that mobility providers such as the ÖBB (an Austrian railway company) become an AMOD provider and use this service to supplement their core business and to increase the use of train services. Furthermore, municipalities can also decide to take on the task of the mobility operator. This option could be considered to promote the establishment of such a service in particularly rural areas.

5.2.2. Mobility Costs

An AMOD service provides a variety of services that can make personal mobility more convenient and more efficient. But as everything in life, this service also has a price. As the service is based on a mobility on-demand model is it obvious that the pricing of a trip will depend on the distance of the trip and the travel time, similar to a regular taxi ride. However, in the previous chapters a variety of options have been discussed regarding the use of the AMOD service developed for Lower Austria. These different use cases indicate that the pricing of the service will also depend on additional factors, next to distance and time.

First of all, if the customer holds the rental service of the vehicle while for example going shopping an additional fee will be charged. Second, discounts can be provided for pre-booked trips and shared rides. Third, depending on the time of day and the current demand, operators may choose to increase the price. This measure can be used to change travel behaviours and to create a more balanced travel demand. For example, people who want to go shopping at 7:00 will soon learn that going shopping by car at 9:00 is cheaper as the travel demand at that time is lower. Fourth, additional fees can be charged for example when the car has to drive a long distance in order to pick up the clients or the customer requests a vehicle but does not use it and forgets to cancel the order.

The exact pricing of each ride will finally depend on the operator. To estimate the price of a ride futher research is necessary. It should however be clear that the price for a trip has to be cheaper than doing the trip with the private car as otherwise people will not switch to this service.

Apart from the costs consumers have to pay, the model will also create costs for the mobility operator. These costs are related to the costs of car ownership. As the vehicles are now owned by the mobility operators instead of private people, the mobiliy providers takes on these costs and customers only face variable costs for each ride and save the sustantial up front costs of car ownership. These bespoke costs are: the purchase price of the autonomous vehicles, insurance, taxes, depreciation, parking, fuel and other service costs. In regards to insurance costs it can be added that it is possible that these will decrease due to the fact that autonomous vehicles are safer than conventional vehicles with human drivers.

5.3. Impacts of the Model on the Mobility in Rural Areas

The findings from chapter 4 of this thesis underline the challenges personal mobility faces in rural areas. People are dependent on their private vehicles, public transportation is limited and people that cannot drive a car a reliant on others to chauffeur them or have to walk. Following the research discussed in chapter 3, mobility on-demand services have the ability to replace expensive car ownership and at the same time let people enjoy the same degree of mobility. When combining mobility on-demand with autonomous vehicles the effects are believed to be even bigger. For this reason, the impacts of the AMOD model developed for Lower Austria on mobility in rural areas are discussed separately in this section.

The biggest potential of autonomous vehicles is that it can provide mobility for all. By taking over the driving task, autonomous vehicles eliminate the need for a driver and hence for people to have a driving licence in order to use the vehicle. This will have a big impact on the mobility of the young and elderly people. These two age groups have so far been restricted from driving car, which makes them reliant on others to drive them to a desired destination. The AMOD model will change this and also allow people who do not have the ability to drive to use the service and to satisfy their travel demand by automobile travel.

Besides providing mobility for all age groups, AMOD can provide the flexibility normally associated with private cars. First of all, a car can be requested spontaneously and according to the demand of the people. Secondly, instead of having to walk to a vehicle, the autonomous vehicle drives up to the customer and can provide a door-to-door service. Third, travelling by car can be enjoyed without having to care about parking, maintenance or other duties that come with car ownership. Fourth, AMOD even has the ability to increase people's flexibility. As the service can be used spontaneously, people when going out to a bar or restaurant do not have to leave their car parked at the venue and pick it up the next day if they had consumed alcohol. Instead these people can request a ride home via the app, just as they probably did at the beginning of the evening.

These reasons for increased flexibility also provide additional convenience to the customers of the AMOD service. In addition to the above bespoke benefits, the model offers further convenience due to the nature of the autonomous vehicles. As the vehicle drives autonomously, the passengers can use the time during the ride as they desire. They can for example read messages, send emails, talk on the phone or just sit back and relax.

The flexible and convenient nature of the service is also enabled by the smartphone app. As described in chapter 5.1 the app makes the access to the AMOD service very easy. By using the app, customers can easily organise their trips and book trips ahead of time, which minimises their wait time. Furthermore, parents can keep track of the travel of their children via the app. The app also allows people have a better overview over their travel costs in general. This convenience is another benefit of the model.

In sum, all these benefits and impacts on mobility in rural areas can ultimately lead to the elimination of the need to own a car or at least to own more than one car. How fast this can be achieved is still unclear, but it makes sense to conclude that the number of benefits AMOD provide to make the switch from car ownership to a AMOD membership possible.

However, for the new mobility model based on AMOD to become successful, it should be pointed out that people will have to change their travel behaviour slightly. In other words, people will have to share more rides especially at peak travel times. Whether this change in behaviour is experienced as negative or not is subject to more research. It is however likely that the advantages of the mobility model prevail, especially when financial incentives are offered to foster ridesharing, and that this change will not be particularly deemed as forced.

5.4. Impacts of the Model on Sustainability

In chapters 2 and 3 the sustainable nature of autonomous vehicles and mobility on-demand models were examined separately. The findings for both concepts were promising. Now, after combining the two concepts in one and applying it to Lower Austria it is time to evaluate whether this model has the potential to provide sustainable mobility. Therefore, the findings from chapters 4 and 5 are examined according to their impact on the 3 pillars of sustainability (economy, environment and society) in this section.

5.4.1. Economy

The mobility system described in this chapter is a mobility system that is not only based on autonomous vehicles, but also functions nearly autonomously. This autonomous nature will have a truly disruptive impact on the economy. Petrol stations will no longer be needed, as the vehicles are powered by electricity and can recharge themselves via inductive wireless charging stations. Driving schools will become obsolete, as people will not be the ones driving any more. Car repair shops and car dealers will close down or merge as more and more people completely switch to the AMOD service. But on the other hand, the use of AMOD for example to get to train stations when travelling to work or school will also diminish the need for park & ride as well as other parking facilities. This will save a lot of money, money that can be invested for other purposes. Furthermore, the model allows the development of new mobility providers. New companies such as car2go, Uber and Lyft that have only been established in the last decade can be founded and have the potential to offer new workplaces.

In addition, AMOD can provide better access to remote areas, which can result in more guests and an increase in tourism. Better access also means that the connection to urban areas improves. This will make it easier for people to commute to work, which could as a consequence mean that AMOD services help to mitigate rural depopulation.

5.4.2. Environment

In regards to the environment, the new mobility model will have a big impact. As the model is based on electric vehicles, which produce no tail pipe emissions, the CO_2 emissions produced by private mobility will be drastically reduced. To ensure that these CO_2 emissions are not produced through the energy generate to power the vehicles, it is important to make sure that this energy is produced from renewable sources. These sources can be hydropower as well as solar, wind and biomass. In the case of Lower Austria, which claims to produce electricity from 100 % renewable sources since 2015, electric vehicles are a clean alternative to vehicles with internal combustion engines. Furthermore, removing humans from the driving task would increase efficiency in respect to energy consumption as well as the driving task itself. Autonomous vehicles tend to brake and accelerate less. This will lead to decreased noise pollution, which will further decrease due to more silent operation of electric vehicles.

5.4.3. Society

Next to providing mobility for all, as identified in the previous chapter, there will be further positive impacts of AMOD on the society. First, removing humans from the driving tasks, increases road safety. This increase in safety will especially be felt by the elderly and young people who tend to be more insecure when driving. Second, the diminished need for park & ride and other parking facilities will not only save costs but also free up space and make it available for new purposes. Third, the use of AMOD by children and elderly people will free other people from the responsibility to pick them up or drop them off and allow these people to use their time more productively. Fourth, the new mobility model is expected to impact the costs of mobility. People that give up their vehicle or households that dispense with their second vehicle will save up front investment costs as well as maintenance costs, insurance, taxes, depreciation, parking, fuel and other service costs. Instead they only pay for the trips they take and can make use of special offers for example for pre-booked trips. Finally, it is possible that public transportation could also become cheaper as they can operate more efficiently and economically.

AMOD will also impact public transportation. The possibility to use AMOD to get to public transportation more conveniently could impact the use of public transportation. This will allow mobility providers of public transport to provide a more efficient service by for example offering high-speed trains that only have a few stops. People will arrive in shorter time at a train station in their proximity and then be able to take an autonomous vehicle to drive home. This will broader establish AMOD as a supplement to public transportation. To complete, another option is that the public transport providers extend train services with respective infrastructure, which will trigger additional investments.

6. Summary and Conclusion

In this thesis a new mobility model for Lower Austria was developed, with the aim to provide sustainable mobility also in rural areas. In order to develop this model two emerging trends in transportation were analysed. Autonomous vehicles and mobility on-demand promise to eliminate the inefficiencies, that have been established in our transport system due to the prominent use of private automobiles. In addition, a mobility study conducted in Lower Austria was examined to identify the travel patterns and needs of the population. Therefore, the developed model is based on the findings and evaluated in respect of its impact on the economy, environment and society.

The findings suggest that autonomous vehicles are going to change the way we think and use personal transportation. Instead of having to drive ourselves, the vehicle will drive us to our desired destination and allow us to use our time more productively. Autonomous vehicles will also be able to complete the driving task more efficiently and decrease GHG emission, road fatalities and congestion.

In contrast, the literature review on mobility on-demand systems highlights that personal transportation systems can also be designed more efficiently. By allowing people to share vehicles and rides, the need for additional travel resources can be reduced. Besides, this allows the use of the already existing one (private and public transportation) more cost- and resource-efficiently.

While the technology of autonomous cars clearly provides many benefits on its own, further findings suggest that its true potential lies in its ability to remove the limitations of mobility on-demand systems and to develop a new mobility system – autonomous mobility on-demand (AMOD). A big advantage of AMOD is that it allows mobility on-demand models to expand to rural areas. As autonomous vehicles can drive to people autonomously and drive them to their desired destination, they are also able to relocate themselves autonomously. This will create a truly free floating mobility system that can rebalance itself, recharge itself and provide mobility to all age groups of a society without human intervention.

The developed model, therefore, consists of three important building blocks: AMOD, a smartphone app and the travel needs and patterns of Lower Austrians. AMOD combines the advantages of autonomous vehicles with the benefits of mobility on-demand. To ensure that the deployment of the model mitigates the negative effects of the current transport system on the environment, the model is based on electric vehicles. A smartphone app than allows to organise the model in time and space, according to the needs of the population. In addition, the app makes the service accessible to all.

The findings of this thesis highlight that AMOD is a concept with the potential to provide sustainable mobility, especially for rural areas and therefore, should not be restricted only to urban transportation. When applying it to rural areas it can help traffic planners to overcome the challenges current transport systems face in these areas. It can save costs for mobility providers as well as customers and at the same time decrease GHG emissions. In addition, AMOD can provide automotive travel to a greater range of people without increasing car ownership. In fact, the opposite could be the case. If designed well the AMOD model has the capability to decrease car ownership, while providing people with the same level of convenience. This will allow transforming the travel patterns found in Lower Austria today into a travel behaviour that favours shared rides over individual travel. Furthermore, nobody is excluded from the use of the service. To the contrary, autonomous vehicles allow the model to be extended to the most remote places.

Of course there are also a number of restrictions to the proposed mobility model. First, the model is based on present travel demand and patterns. This will change with time and also be influenced by the model itself. Second, the model is based on a number of technological developments that have not been completed yet. Third, the model is designed to provide for short-distance travel. Long-distances trips such as holiday trips cannot be done solely with this proposed model. Fourth, the deployment of the model should be in stages. It will take time for the model to reach all regions in Lower Austria and it will require a learning and adjustment phase. Fifth, for the model to successfully provide sustainable mobility people will have to change their travel behaviour and share more rides. Sixth, before the model can be deployed technical and legal issues such as data security and protection have to be addressed, questions of liability have to be answered, and the regulatory framework has to be adjusted. Seventh, the deployment of the model depends on political support and economic feasibility.

In order to evaluate the real feasibility of this proposed concept, additional research has to be conducted. This research should cover the above-mentioned restrictions, which ultimately represent the research questions a final feasibility study will have to answer.

To bring the building blocks together and to ensure a successful implementation of the proposed model, Lower Austria should become active now. It should already start talks with all stakeholders and representatives of interests groups. Once an open dialogue and discussion forum is established the federal state can ensure that hindering obstacles are identified and removed, that the efforts of the involved parties move in a common direction and that the necessary legal and technical issues are addressed. Autonomous vehicle technology is developing fast and Lower Austria should be ready when these vehicles hit the roads.

A further reason to start preparing for autonomous vehicles now is that while this thesis has concentrated on the potential of AMOD using fully autonomous vehicles, research indicates that starting from level 3 automation autonomous vehicles can already enhance mobility on-demand models. With level 3, automated vehicles are able to drive safely under certain conditions. This will allow carsharing vehicles to slowly drive up to customers and save them from walking to the vehicle (Greenblatt and Shaheen 2015). Furthermore, it will provide for self-parking and self-recharging (Greenblatt and Shaheen 2015).

As the EEA Executive Director, Jaquelin McGlade emphasised "one of the big challenges of the 21st Century will be to mitigate the negative effects of transport […] while ensuring positive aspects of mobility" (EEA 2012). AMOD provides a promising solution to this challenge and this thesis shows a clear path of deployment for Lower Austria. Now, it is up to the federal state to ensure that this concept is successfully implemented.

Bibliography

Ahsan, Sadaf, and Laura Hensley. *Summer of Uber: Everything you need to know about the upstart ride-sharing service.* 21. Aug 2015. http://www.nationalpost.com/m/wp/blog.html?b=news.nationalpost.com%2F%2Fnews%2Fcanada%2Fsummer-of-uber-everything-you-need-to-know-about-the-upstart-ride-sharing-service&utm_content=buffer0e403&utm_medium=social&utm_source=facebook.com&utm_campaign=buffer (Accessed 01. Sep 2015).

Alessandrini, Adriano, Andrea Campagna, Paolo Delle Site, Francesco Filippi, and Luca Persia. „Automated Vehicles and the Rethinking of Mobility and Cities." *Transportation Research Procedia* 5 (2015): 145-160.

Alessandrini, Adriano, Andrea Campagna, Paolo Delle Site, Francesco Filippi, and Luca Persia. „Automated Vehicles and the Rethinking of Mobility and Cities." *Transportation Research Procedia* 5 (2015): 145-160.

Alessandrini, Adriano, Andrea Campagna, Paolo Delle Site, Francesco Filippi, and Luca Persia. „Automoted Vehicles and the Rethinking of Mobility and Cities." *Transportation Research Procedia*, Nr. 5 (2015): 145-160.

Amt der NÖ Landesregierung. *Kleinräumige Mobilitätsangebote. Empfehlungen für die praktische Umsetzung.* Heft 29, St. Pölten: Amt der NÖ Landesregierung, 2012.

—. „Wohnbevölkerung 2014 nach Alter und Gemeinden." *Zahlen und Fakten in Niederösterreich.* 01. Jan 2014. http://www.noe.gv.at/bilder/d85/Bevstruktur_Alter_2014.xlsx (Accessed 18. Sep 2015).

Anderson, James M., Nidhi Kalra, Karlyn D. Stanley, Paul Sorensen, Constantine Samaras, and Oluwatobi A. Oluwatola. *Autonomous Vehicles Technology: A Guide for Policymakers.* report, Washington: RAND, 2014.

APA. *ASFINAG investiert 2016 eine Milliarde Euro in Autobahnen und Schnellstraßen.* 16. Feb 2016. http://www.ots.at/presseaussendung/OTS_20160222_OTS0130/asfinag-investiert-2016-eine-milliarde-euro-in-autobahnen-und-schnellstrassen (Accessed 15. Apr 2016).

Audi. *04 Journal: Audi piloted driving.* N.A. http://www.audi.com/com/brand/en/vorsprung_durch_technik/content/2014/10/piloted-driving.html (Accessed 04. Feb 2016).

Automotive Council UK. *Driverless cars technology receives £20 million boost.* 01. Feb 2016. http://www.automotivecouncil.co.uk/2016/02/driverless-cars-technology-receives-20-million-boost/ (Accessed 16. Apr 2016).

Barthelemy, Pierre Antoine, and Claude Vidal. *Der ländliche Raum der Europäischen Union.* N.A. http://ec.europa.eu/agriculture/envir/report/de/rur_de/report.htm (Accessed 30. Apr 2016).

Berman, Bradley. *Drivers Push Tesla's Autopilot Beyond Its Abilities.* 21. Oct 2015. https://www.technologyreview.com/s/542651/drivers-push-teslas-autopilot-beyond-its-abilities/ (Accessed 04. Feb 2016).

Blanco, Sebastian. *Car2go turns your smartphone into carsharing key with Mobile Access.* 24. Nov 2014. http://www.autoblog.com/2014/11/24/car2go-turns-your-smartphone-into-carsharing-key-mobile-access/ (Accessed 21. Apr 2016).

BMVI. *Automated Driving.* N.A a. http://www.bmvi.de/EN/TransportAndMobility/Mobility/AutomatedDriving/automated-driving_node.html (Accessed 12. Apr 2016).

—. *Dobrindt launches Digital Motorway Test Bed.* 04. Sep 2015 b. http://www.bmvi.de/SharedDocs/EN/Pressemitteilung/2015/084-dobrindt-launches-digital-motorway-test-bed.html (Accessed 15. Apr 2016).

BMVIT. „Austrian Research, Development & Innovation Roadmap for Automated Vehicles.“ *Die Österreichische Forschungsförderungsgesellschaft.* Feb 2016. https://www.ffg.at/sites/default/files/downloads/call/austrian_roadmap_automated_vehicles.pdf (Accessed 16. Apr 2016).

BMVIT. *Mobilität im Alter. Ein Handbuch für PlanerInnen, EntscheidungsträgerInnen und InteressensvertreterInnen.* report, Wien: Bundesministerium für Verkehr, Innovation und Technologie, 2013.

—. *Road Safety in Austria Annual Report 2014.* 2014. https://www.bmvit.gv.at/en/service/publications/transport/downloads/roadsafety_report2014.pdf (Accessed 16. Apr 2016).

BMVIT. *Verkehr in Zahlen: Österreich, Ausgabe 2011.* report, Wien: BMVIT, 2011.

BMW Group. *Automated Driving: The future of the smart car.* 2016. https://www.bmwgroup.com/en/innovation/technologies-and-mobility/automated-driving.html (Accessed 12. Apr 2016).

Boeriu, Horatiu B. *BMW R&D chief talks about the future of autonomous driving.* 15. Nov 2015. http://www.bmwblog.com/2015/11/15/bmw-rd-chief-talks-about-the-future-of-autonomous-driving/ (Accessed 04. Feb 2016).

Borrmann, Daniel. „Electric operability of an inductive charging system for electric vehicles in an urban area.“ *Electric Drives Production Conference (EDPC), 2014 4th International*, 2014: 1 - 8.

Bowdler, Neil. *Wirelessly charged electric buses set for Milton Keynes .* 09. Jan 2014. http://www.bbc.com/news/technology-25621426 (Accessed 08. May 2016).

Bradlow, Hugh, and Arjun Jayachandra. *How digitial infrstructure can substitute for physical infrastructure.* paper, Sydney: United States Studies Centre, 2015.

Brown, Austin, Jeffrey Gonder, and Brittany Repac. „An Analysis of Possible Energy Impacts of Automated Vehicle.“ In *Road Vehicle Automation, Lecture Notes in Mobility*, von Gereon Meyer and Sven Beiker, 137-153. Cham: Springer International Publishing, 2014.

Bullis, Kevin. *How Vehicle Automation Will Cut Fuel Consumption.* 24. Oct 2011. https://www.technologyreview.com/s/425850/how-vehicle-automation-will-cut-fuel-consumption/ (Accessed 16. Apr 2016).

Burns, Lawrence D., William C. Jordan, and Bonnie A. Scarborough. „Transforming Personal Mobility .“ *The Earth Institute, Columbia University.* 27. Jan 2013. http://sustainablemobility.ei.columbia.edu/files/2012/12/Transforming-Personal-Mobility-Jan-27-20132.pdf (Accessed 05. Apr 2016).

Buzzacco-Foerster, Jenna. *Open Roads: Florida preparing for self-driving vehicles*. 11. Apr 2016. http://floridapolitics.com/archives/206633-open-roads-florida-preparing-self-driving-vehicles (Accessed 13. Apr 2016).

car2go Österreich GmbH. *How does it work?* 2016 c. https://www.car2go.com/en/wien/how-does-car2go-work/ (Accessed 21. Apr 2016).

—. *What does it cost?* 2016 b. https://www.car2go.com/en/wien/what-does-car2go-cost/ (Accessed 21. Apr 2016).

—. *What is car2go?* 2016 a. https://www.car2go.com/en/wien/what-is-car2go/ (Accessed 21. Apr 2016).

car2go. *Zwei Jahre Free Floating in Wien: car2go feiert Geburtstag in der österreichischen Hauptstadt!* 08. Jan 2014. http://blog.car2go.com/2014/01/08/zwei-jahre-free-floating-in-wien-car2go-feiert-geburtstag-in-der-osterreichischen-hauptstadt/ (Accessed 20. Sep 2015).

Catapult. *LUTZ Pathfinder automated pods project.* N.A. https://ts.catapult.org.uk/pods (Accessed 16. Apr 2016).

Chan, Nelson, and Susan Shaheen. „Ridesharing in North America: Past, Present, and Future.“ *Transport Reviews* 32, Nr. 1 (2012): 93-112.

Chong, Z.J., et al. „Autonomy for Mobility on Demand.“ In *Intelligent Autonomous Systems*, von Sukhan Lee, Hyungsuck Cho, Kwang-Joon Yoon and Jangmyung Lee, 671-682. Berlin Heidelberg: Springer-Verlag, 2013.

Chow, Denise. *DARPA and Drone Cars: How the US Military Spawned Self-Driving Car Revolution.* 21. Mar 2014. http://www.livescience.com/44272-darpa-self-driving-car-revolution.html (Accessed 12. Apr 2016).

Chu, Jennifer. *New algorithm finds best routes for one-way car sharing.* 24. Jun 2013. http://news.mit.edu/2013/algorithm-finds-best-routes-for-one-way-car-sharing-0624 (Accessed 22. Apr 2016).

DARPA. *Grand Challenge Overview.* 28. Nov 2007. http://archive.darpa.mil/grandchallenge/overview.html (Accessed 10. 04 2016).

Department for Transport. „The Pathway to Driverless Cars: A Code of Practice for testing.“ *UK Government.* Jul 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/446316/pathway-driverless-cars.pdf (Accessed 15. Apr 2016).

DIRECTIVE 2010/40/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 7 July 2010 on the framework for the deployment of Intelligent Transport Systems in the field of road transport and for interfaces with other modes of transport [2010] OJ L207/1

Dijkstra, Lewis, and Hugo Poelman. *A harmonised definition of cities and rural areas: the new degree of urbanisation. Regional Working Paper 2014.* working paper, Brussels: European Commission, 2014.

DMV. *Autonomous Vehicles in California.* 22. Mar 2016. https://www.dmv.ca.gov/portal/dmv/detail/vr/autonomous/testing (Accessed 12. Apr 2016).

—. *Regulations Clear the Road for Self-driving Cars.* 15. Feb 2012. http://www.dmvnv.com/news/12001-regulations-for-self-driving-cars.htm (Accessed 13. Apr 2016).

Dokic, Jadranka, Beate Müller, and Gereon Meyer. *European Roadmap Smart Systems for Automated Driving .* report, Berlin: EPoSS , 2015.

ECMT (European Council of Ministers of Transport). *Transport/Telecommunications*. 2340th Council Meeting, 7587/01 (Presse 131), Luxembourg 4 – 5 April 2001. http://europa.eu/rapid/press-release_PRES-01-131_en.htm?locale=en, Accessed Jan 24, 2016.

EEA. *Traffic pollution still harmful to health in many parts of Europe .* 22. Nov 2012. http://www.eea.europa.eu/media/newsreleases/traffic-pollution-still-harmful-to (Accessed 02. Feb 2016).

EPoSS. „EPoSS Roadmap "Smart Systems for Automated Driving" now published.“ *European Roadmap Smart Systems for Automated Driving.* 2015. http://www.smart-systems-integration.org/public/documents/publications/EPoSS%20Roadmap_Smart%20Systems%20for%20Automated%20Driving_V2_April%202015.pdf (Accessed 10. Jan 2016).

European Commission . *Road safety in the European Union Trends, statistics and main challenges, March 2015.* report, Brussels: European Union, 2015 b.

—. *Rolling plan for ICT standardisation.* 26. Mar 2015 c. https://ec.europa.eu/digital-single-market/rolling-plan-ict-standardisation (Accessed 16. Apr 2016).

European Commission. *2050 low-carbon economy.* 06. Oct 2015. http://ec.europa.eu/clima/policies/strategies/2050/index_en.htm (Accessed 07. Oct 2015).

—. *Intelligent Transport: sector issues guidance on how the EU can make the most of connected cars.* 21. Jan 2016. http://ec.europa.eu/transport/themes/its/news/2016-01-21-c-its_en.htm (Accessed 12. Apr 2016).

European Commisssion . *White Paper on Transport: Roadmap to a Single European Transport Area — towards a competitive and Resource-efficient Transport System.* White Paper, Luxembourg: European Union, 2011.

Fagnant, Daniel J., and Kara M. Kockelman. *Preparing a Nation for Autonomous Vehicles: Opportunities, Barriers and Policy Recommendations.* Washington: Eno Center for Transportation, Oct 2013.

Firnkorn, Jörg, and Martin Müller. „What will be the environmental effects of new free-floating car-sharing systems? The case of car2go in Ulm.“ *Ecological Economics* 70, Nr. 8 (2011): 1519–1528.

Fournier, Guy, René Seign, Véronique Goehlich, and Klaus Bogenberger. „Car-sharing with electric vehicles: a contribution to sustainable mobility?“ *Interdisciplinary Management Research* 11 (2015): 955-975.

Golem Media GmbH. *Jerry Brown unterzeichnet Gesetz für Roboterautos.* 26. Sep 2012. http://video.golem.de/politik-recht/9324/gouverneur-jerry-brown-unterzeichnet-gesetz-fuer-roboterautos.html (Accessed 04. Feb 2016).

Gonder, J, M Earleywine, and W Sparks. „Analyzing vehicle fuel saving opportunities through intelligent driver feedback.“ *SAE International Journal Passeng Cars Electron Electric Systems* 5, Nr. 2 (2012): 450–461.

Goodall, Warwick, Tiffany Fishmann, Simon Dixon, and Costi Perricos. *Transport in the Digital Age. Disruptive Trends for Smart Mobility.* report, London: Deloitte LLP, 2015.

Google . *What’s the difference between fully self-driving cars and driver assistance?* N.A a. https://www.google.com/selfdrivingcar/faq/ (Accessed 04. Feb 2016).

Google. „Google Self-Driving Car Project: Monthly Report, April 2016.“ *Google Self-Driving Car Project .* 30. Apr 2016 a. https://static.googleusercontent.com/media/www.google.com/de//selfdrivingcar/files/reports/report-0416.pdf (Accessed 13. May 2016).

—. *Google Self-Driving Car Project: Where we’ve been.* N.A b. https://www.google.com/selfdrivingcar/where/ (Accessed 04. Feb 2016).

—. *Monthly reports.* 30. Apr 2016 b. https://www.google.com/selfdrivingcar/reports/ (Accessed 13. May 2016).

GOV.UK. *Driverless cars: 4 cities get green light for everyday trials.* 04. Dec 2014. https://www.gov.uk/government/news/driverless-cars-4-cities-get-green-light-for-everyday-trials (Accessed 16. Apr 2016).

—. *Driverless vehicles: connected and autonomous technologies.* 14. Apr 2016. https://www.gov.uk/government/collections/driverless-vehicles-connected-and-autonomous-technologies (Accessed 16. Apr 2016).

Greenblatt, Jeffery B., and Samveg Saxena. „Autonomous taxis could greatly reduce greenhouse-gas emissions of US light-duty vehicles.“ *Nature Climate Change* 5 (2015): 860–863.

Greenblatt, Jeffery B., and Susan Shaheen. „Automated Vehicles, On-Demand Mobility, and Environmental Impacts.“ *Current Sustainable/Renewable Energy Reports* (Springer International Publishing) 2, Nr. 3 (2015): 74-81.

Harris, Mark. *Uber: why the world's biggest ride-sharing company has no drivers.* 16. Nov 2015. https://www.theguardian.com/technology/2015/nov/16/uber-worlds-biggest-ride-sharing-company-no-drivers (Accessed 24. Apr 2016).

Hawkins, Andrew J. *Uber covers 75 percent of the US, but getting to 100 will be really hard.* 23. Oct 2015. http://www.theverge.com/2015/10/23/9603324/uber-coverage-rural-areas-dominance-plan (Accessed 20. Apr 2016).

Hellåker, Jan. *About Drive Sweden.* N.A. http://www.drivesweden.net/en/about-drive-sweden (Accessed 16. Apr 2016).

Herry Consult GmbH. *Mobilität in NÖ. Ergebnisse der landesweiten Mobilitätsbefragung 2008.* report, St. Pölten: Amt der NÖ Landesregierung, 2009.

Herry Consult GmbH. *Verkehr in Zahlen, Österreich Ausgabe 2011.* report, Wien: BMVIT, 2012.

Hong, Qiang, Richard Wallace, and Gregory Krueger. *Connected vs. automated vehicles as generators of useful data.* report, Michigan Department of Transportation, Centre for Automotive Research, and Leidos Inc., 2014.

IEA. *CO2 EMISSIONS FROM FUEL COMBUSTION (2015 Edition).* Paris: OECD/IEA, 2015.

—. „ENERGY SUPPLY SECURITY 2014. Emergency response systems of individual IEA countries. Austria.“ *IEA.* 2014. https://www.iea.org/media/freepublications/security/EnergySupplySecurity2014_Austria.pdf (Accessed 15. Apr 2016).

—. *Transport, Energy and CO2: Moving Toward Sustainability.* 2009. https://www.iea.org/publications/freepublications/publication/transport2009.pdf (Accessed 31. Aug 2015).

Innovative UK. *Introducing driverless cars to UK roads.* N.A. https://interact.innovateuk.org/competition-display-page/-/asset_publisher/RqEt2AKmEBhi/content/introducing-driverless-cars-to-uk-roads?p_p_auth=CjGJE10t (Accessed 16. Apr 2016).

INRIX. *Key Findings: Urban Mobility Scorecard Annual Report.* 2014. http://www.inrix.com/scorecard/key-findings-us/ (Accessed 06. Feb 2016).

ITF. *Automoated and Autonomous Driving: Regulation under undertainty.* report, Paris: OECD, Inernational Transport Forum, 2015.

ITS Japan. *ITS initiatives in Japan.* July 2012. http://www.mlit.go.jp/road/ITS/pdf/ITSinitiativesinJapan.pdf (Accessed 13. Apr 2016).

Jaynes, Nick. *Three autonomous Mercedes-Benz trucks just platooned across Europe.* 06. Apr 2016. http://mashable.com/2016/04/05/mercedes-actros-platoon-europe/#ZHvT6455yPqZ (Accessed 16. Apr 2016).

Kilimann, Susanne. *Community, entwickle ein Auto.* 03. Aug 2015. http://www.zeit.de/mobilitaet/2015-08/local-motors-auto-regionale-produktion-berlin (Accessed 16. Apr 2016).

Koderhold, Matthias. *Einkommen 2014 in Niederösterreicher.* report, Wien: AKNÖ, 2015.

Kokalitcheva, Kia. *Lyft Expands Short-Distance Carpool Service Into 6 New Areas.* 05. Apr 2016. http://fortune.com/2016/04/05/lyft-line-expansion/ (Accessed 20. Apr 2016).

Korosec, Kirsten. *Elon Musk Says Tesla Vehicles Will Drive Themselves in Two Years.* 21. Dec 2015. http://fortune.com/2015/12/21/elon-musk-interview/?xid=yahoo_fortune (Accessed 04. Feb 2016).

Kronister, Thomas. *Analyse Pendeln in NÖ, Zahlen und Fakten 2014.* report, Wien: AKNÖ, 2015.

Landmann, Ralf H., Jan-philipp Hasenberg, and Christian Weber. „Shift in Young Mobility. Young Mobility Survey 2011: Challenges and opportunities." *Automotive Insights* (Roland Berger Strategy Consultants GmbH) 1 (2011): 20-25.

Le Vine, Scott, Alireza Zolfaghari, and John Polak. „Carsharing: Evolution, Challenges and Opportunities." *ACEA.* Sep 2014. https://www.acea.be/uploads/publications/SAG_Report_-_Car_Sharing.pdf (Accessed 18. Apr 2016).

Litman, Todd. „Autonomous Vehicle Implementation Predictions: Implications for Transport Planning ." *Victoria Transport Policy Institute .* 24. Aug 2015. http://www.vtpi.org/avip.pdf (Accessed 25. Sep 2015).

LTA and ITS Singapore. *Smart Mobility 2030.* report, Singapore: LTA, 2014.

LTA. *Joint release by the LTA, JTC and A*STAR- A SAVI step towards autonomous transport .* 27. Aug 2014. http://www.lta.gov.sg/apps/news/page.aspx?c=2&id=29525082-5265-4139-bc3b-0241a4639d46 (Accessed 13. Apr 2016).

Lu, Ning, Nan Cheng, Ning Zhang, Xuemin Shen, and Jon W. Mark. „Connected Vehicles: Solutions and Challenges." *IEEE Internet of Things Journal* 1, Nr. 4 (Aug 2014): 289-299.

Lukic, Srdjan, and Zeljko Pantic. „Cutting the Cord: Static and dynamic inductive wireless charging of electric vehicles." *IEEE Electrification Magazine* 1, Nr. 1 (Sep 2013): 57-64.

Martin, Elliot W., and Susan A. Shaheen. „Greenhouse Gas Emission Impacts of Carsharing in North America." *IEEE Transactions on intelligent Transportation systems* 12, Nr. 4 (2011): 1074-1086.

Mercedes-Benz. *Autonomous long-distance drive.* 2016. https://www.mercedes-benz.com/en/mercedes-benz/innovation/autonomous-long-distance-drive/ (Accessed 12. Apr 2016).

Michigan goverment. *Snyder signs bills allowing driverless vehicles in Michigan.* 2013. http://www.michigan.gov/snyder/0,4668,7-277-57577-318728--,00.html (Accessed 12. Apr 2016).

MindTake. *Mobile Communications Report 2015.* report, Wien: MMA Austria, 2015.

Mitchell, William J., and et.al. *Mobility on Demand. Future of transportation in cities.* MIT Media Laboratory, 2008.

MLIT. *Deploying Land, Infrastructure, Transport and Tourism Administration Tailored to Urges of the Times.* 2014. http://www.mlit.go.jp/common/001113562.pdf (Accessed 13. Apr 2016).

Murry, Sarah. *Wireless Tech is Only the Beginning in the Connected Car.* 15. Sep 2015. http://www.broadcom.com/blog/automotive-technology-2/wireless-tech-is-only-the-beginning-in-the-connected-car/ (Accessed 12. Apr 2016).

Navigant Research. *Research Report Executive Summary: Autonomous Vehicles.* 2015. https://www.navigantresearch.com/wp-assets/brochures/ASDV-15-Executive-Summary.pdf (Accessed 12. Apr 2016).

Nealer, Rachael, David Reichmuth, and Don Anair. „Cleaner Cars from Cradle to Grave: How Electric Cars Beat Gasoline Cars on Lifetime Global Warming Emissions.“ *Union of Concerned Scientists.* Nov 2015. http://www.ucsusa.org/sites/default/files/attach/2015/11/Cleaner-Cars-from-Cradle-to-Grave-full-report.pdf (Accessed 14. Apr 2016).

Nelson, Gabe. *Google car project finds friends in industry.* 19. Jan 2015. http://www.autonews.com/article/20150119/OEM09/301199949/google-car-project-finds-friends-in-industry (Accessed 04. Feb 2016).

Newcomer, Eric. *Uber Said to Seek $1.5 Billion in Funds at $50 Billion Valuation.* 09. May 2015. http://www.bloomberg.com/news/articles/2015-05-09/uber-said-to-seek-1-5-billion-in-funds-at-50-billion-valuation (Accessed 01. Sep 2015).

NHTSA. „Preliminary Statement of Policy Concerning Automated Vehicles .“ *National Hightway Traffic Safety Administration.* 13. May 2013. http://www.nhtsa.gov/staticfiles/rulemaking/pdf/Automated_Vehicles_Policy.pdf. (Accessed 03. Feb 2016).

—. *Secretary Foxx unveils President Obama’s FY17 budget proposal of nearly $4 billion for automated vehicles and announces DOT initiatives to accelerate vehicle safety innovations .* 14. Jan 2016. http://www.nhtsa.gov/About+NHTSA/Press+Releases/dot-initiatives-accelerating-vehicle-safety-innovations-01142016 (Accessed 13. Apr 2016).

Nissan. *Nissan's Autonomous Drive Car.* 14. Mar 2014. http://www.nissanusa.com/blog/autonomous-drive-car (Accessed 12. Apr 2016).

OICA. *2014 Production Statistics.* 2014. http://www.oica.net/category/production-statistics/2014-statistics/ (Accessed 16. Apr 2016).

Olia, Arash, Hossam Abdelgawad, Baher Abdulhai, and Saiedeh N. Razavi. „Assessing the Potential Impacts of Connected Vehicles: Mobility, Environmental, and Safety Perspectives.“ *Journal of Intelligent Transportation Systems*, 2015: 1-15.

Pavone, Marco. „Autonomous Mobility-on-Demand Systems for Future Urban Mobility.“ In *Autonomes Fahren*, von Markus Maurer, J. Christian Gerdes, Barbara Lenz and Hermann Winner, 399-416. Berlin Heidelberg: Springer-Verlag, 2015.

Phenix, Matthew. *Hands off with Heathrow's autonomous pod cars.* 13. Nov 2014. http://www.bbc.com/autos/story/20140910-hands-off-with-heathrows-pods (Accessed 16. Apr 2016).

Pillath, Susanne. „Automated vehicles in the EU.“ *European Parliament Think Tank.* 07. Jan 2016.

http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573902/EPRS_BRI(2016)573902_EN.pdf (Accessed 29. Jan 2016).

Pinelis, Mike. *Automotive sensors and elctronics: Trend and developments in 2013.* Expo, Detroit: Automotive Sensors Electronics, 2013.

RAND. *Autonomous Vehicles Technology: A Guide for Policymakers.* report, Washington: RAND, 2014.

Rayle, Lisa, Susan Shaheen, Nelson Chan, Danielle Dai, and Robert Cervero. *App-Based, On-Demand Ride Services: Comparing Taxi and Ridesourcing Trips and User Characteristics in San Francisco.* working paper, University of California Transportation Center, 2014.

Robarts, Stu. *UK roads to become connected and autonomous vehicle test-track.* 02. Feb 2016. http://www.gizmag.com/uk-connected-intelligent-transport-environment/41621/ (Accessed 16. Apr 2016).

Ruhrort, Lisa, Josephine Steiner, Andreas Graff, Daniel Hinkeldein, and Christian Hoffmann. „Carsharing with electric vehicles in the context of users' mobility needs - results from user-centred research from the BeMobility field trail (Berlin).“ *Internationl Journal Technology and Management* 14 (2014): 286-305.

SAE International. „Automated Driving Levels of Driving Automation are defined in new SAE International Standard J3016.“ *SAE International.* 02. Oct 2014. http://www.sae.org/misc/pdfs/automated_driving.pdf (Accessed 03. Feb 2016).

Shaheen, Susan. „Shared-Use Vehicle Services for Sustainable Transportation: Carsharing, Bikesharing, and Personal Vehicle Sharing across the Globe.“ (International Journal of Sustainable Transportation) 7, Nr. 1 (2013): 1-4.

Shaheen, Susan, Adam Cohen, and Roberts Darius. „Carsharing in North America: Market Growth, Current Developments, and Future Potential.“ *Transportation Research Record* 1986 (2006): 106-115.

Shaheen, Susan, Mark Mallery, and Karla Kingsley. „Personal vehicle sharing services in North America.“ *Research in Transportation Business & Management Please cite this article as: Shaheen, S.A., et al., Personal vehicle sharing services in North America, Research in Transportation Business & Man- agement (2012), doi: 10.1016/j.rtbm.2012.04.005* 3 (2012): 71-81.

Shaheen, Susan, Nelson Chan, Apaar Bansal, and Adam Cohen. „Shared Mobility: Definitions, Industry Developments, and Early Understanding. Bikesharing, Carsharing, On-Demand Ride Services, Ridesharing, Shared-Use Mobility.“ *Innovative Mobility Research.* 03. Nov 2015. http://innovativemobility.org/wp-content/uploads/2015/11/SharedMobility_WhitePaper_FINAL.pdf (Accessed 18. Apr 2016).

Shaheen, Susan, and Adam Cohen. „Innovative Mobility Carsharing Outlook. Carsharing Market Overview, Analysis, and Trends Winter 2016.“ *The Transportation Sustainability Research Center of theUniversityofCalifornia, Berkeley.* 02. Feb 2015. http://tsrc.berkeley.edu/sites/default/files/Innovative%20Mobility%20Industry%20Outlook_World%202016%20Final.pdf (Accessed 18. Apr 2016).

Shaheen, Susan, and Nelson Chan. „Mobility and the Sharing Economy: Impacts Synopsis. Shared-Use Mobility Definitions and Impacts, Special Edition.“ *Transportation Sustainability Research Center.* 2015. http://tsrc.berkeley.edu/sites/default/files/Innovative-Mobility-Industry-Outlook_SM-Spring-2015.pdf (Accessed 25. Apr 2014).

Shladover, Steven, Su Dongyan, and Lu Xiao-Yun. „Impacts of Cooperative Adaptive Cruise Control on Freeway Traffic Flow." *Transportation Research Record*, 2012: 63-70.

Shoup, Donald. „Cruising for Parking." *Transport Policy* 13 (2006): 479–486.

Silberg, Gary, and Richard Wallace. *KPMG and CAR: Self-driving cars: The next revolution.* report, Chicago: KPMG , 2012.

Sivak, Michael, and Brandon Schoettle. „Recent Changes in the Age Composition of Drivers in 15 Countries." *Traffic Injury Prevention* 13, Nr. 2 (2012): 126-132.

Sivak, Michael, and Brandon Schoettle. *Road Safety with Self-Driving Vehicles: General Limitations and Road Sharing with Conventional Vehicles.* Report UMTRI-2015-2, Michigan: University of Michigan, 2015.

smile mobility. *smile – simply mobile. The future of mobility.* 2015. http://smile-einfachmobil.at/ (Accessed 08. May 2016).

Smith, W. B. *Automoated and Autonomous Driving: Regulation under undertainty.* report, Paris: OECD, Inernational Transport Forum, 2015.

Sperling, Daniel, and Eileen Claussen. „Motorizing the Developing World." *Science and Technology*, 2002: 59–66.

Spieser, Kevin, Kyle Treleaven, Rick Zhang, Emilio Frazzoli, Daniel Morton, and Marco Pavone. „Toward a Systematic Approach to the Design and Evaluation of Automated Mobility-on-Demand Systems: A Case Study in Singapore." In *Road Vehicle Automation, Lecture Notes in Mobility*, von G. Meyer and S. Beiker, 229-245. Chem: Springer International Publishing, 2014.

Stastica. *Outlook on worldwide light vehicle sales from 2011 to 2020 (in million units).* 2016. http://www.statista.com/statistics/267128/outlook-on-worldwide-passenger-car-sales/ (Accessed 16. Apr 2016).

statista. *Statistics and facts on mobile internet usage.* 2016. http://www.statista.com/topics/779/mobile-internet/ (Accessed 20. Apr 2016).

Statistik Austria. „Stadt-Land - Bevölkerung nach Altersgruppen und Geschlecht - NUTS 3." *Stadt-Land.* 01. Jan 2013. http://www.statistik.at/web_de/klassifikationen/regionale_gliederungen/stadt_land/index.html (Accessed 07. Nov 2015).

—.*Vorausberechnete Bevölkerungsstruktur für Niederösterreich 2013-2075 laut Hauptszenario.* 07. May 2015. http://www.statistik.at/web_de/statistiken/menschen_und_gesellschaft/bevoelkerung/demographische_prognosen/bevoelkerungsprognosen/027311.html (Accessed 20. Sep 2015).

—. „Kfz-Neuzulassungen Jänner bis Dezember 2015." *STATISTIK AUSTRIA.* 21. Apr 2016. http://www.statistik.at/wcm/idc/idcplg?IdcService=GET_PDF_FILE&RevisionSelectionMethod=LatestReleased&dDocName=080836 (Accessed 25. Apr 2016).

Swedish Transport Agency. „Autonomous driving: Short version/Summary." *Transport Styrelsen.* Aug 2014. http://www.transportstyrelsen.se/globalassets/global/press/autonomous-driving_eng_short.pdf?_t_id=1B2M2Y8AsgTpgAmY7PhCfg%3d%3d&_t_q=autonomous+vehicles&_t_tags=language%3aen&_t_ip=193.182.52.35&_t_hit.id=TS_Externwebb_Models_Files_PdfContent/_cba0cc4e-296c-47a7-819a-67e7e04cbea9&_t_hit.pos=4 (Accessed 16. Apr 2016).

Tesla Motors Team. *Your Autopilot has arrived* . 14. Oct 2015. https://www.teslamotors.com/blog/your-autopilot-has-arrived (Accessed 04. Feb 2016).

The Economist. *If autonomous vehicles rule the world: From horseless to driverless.* Aug 2015. http://worldif.economist.com/article/11/what-if-autonomous-vehicles-rule-the-world-from-horseless-to-driverless (Accessed 22. Jan 2016).

Thomas, Peter. *The long-haul truck of the future.* N.A. https://www.mercedes-benz.com/en/mercedes-benz/innovation/the-long-haul-truck-of-the-future/ (Accessed 16. Apr 2016).

Uber. *Always the ride you want.* N.A. b. https://www.uber.com/ride/ (Accessed 20. Apr 2016).

—. *Das Unternehmen.* N.A. a. https://www.uber.com/about (Accessed 01. Sep 2015).

Uber Newsroom. *Announcing UberPool.* 05. Apr 2016. https://newsroom.uber.com/announcing-uberpool/ (Accessed 20. Apr 2016).

Uber. *Trip safety.* N.A. c. https://www.uber.com/ride/safety/ (Accessed 18. Apr 2016).

Uhlemann, Elisabeth. „Introducing Connected Vehicles." *IEEE Vehicular Technology Magazine* , Mar 2015: 23-31.

Umweltamt. *Austria's annual Greenhouse Gas Inventory 1990–2012, Submission under Regulation 525/2013/EC.* Report, Vienna: Umweltamt, 2014.

UN.1968. Vienna Convention on Road and Traffic, May 21, 1977. *UNTS* 1042, no. 15705.

Undercoffler, David. *Toyota won't rush to fully autonomous vehicles, Lentz says.* 12. Jan 2016. http://www.autonews.com/article/20160112/OEM09/160119852/toyota-wont-rush-to-fully-autonomous-vehicles-lentz-says (Accessed 04. Feb 2016).

US DOT. *Automation Research at the USDOT.* 27. Oct 2015 a. http://www.its.dot.gov/automated_vehicle/avr_plan.htm (Accessed 13. Apr 2016).

—. *Connected Vehicle Applications Supported by ITS Standards.* N.A. https://www.standards.its.dot.gov/LearnAboutStandards/CV_apps (Accessed 16. Apr 2016).

—. *Connected Vehicle Technology Standards.* 27. Oct 2015 b. http://www.its.dot.gov/connected_vehicle/connected_vehicle_standards_plan.htm (Accessed 13. Apr 2016).

Viechnicki, Peter, Abhijit Khuperkar, Tiffany Dovey Fishman, and William D. Eggers. *Reducing congestion and fostering faster, greener, and cheaper transportation options.* report, London: Deloitte University Press, 2015.

Volvo Car Corp. *Progress through Partnership.* N.A. a. http://www.volvocars.com/intl/about/our-innovation-brands/intellisafe/intellisafe-autopilot/drive-me/progress-through-partnership (Accessed 16. Apr 2016).

—. *The thoughest test of all - real life.* N.A b. http://www.volvocars.com/intl/about/our-innovation-brands/intellisafe/intellisafe-autopilot/drive-me/real-life (Accessed 16. Apr 2016).

Wallace, Richard, and Gary Silberg. *Self-driving cars: The next revolution kpmg.* white paper, Ann Arbor: KPMG and CAR , 2012.

Wood, Eric, Jeffrey Gonder, and Sai Rajagopalan. „Connectivity-enhanced route selection and adaptive control for the Chevrolet Volt." *National Renewable Energy Laboratory.* 22. Oct 2013. http://www.nrel.gov/docs/fy14osti/60543.pdf (Accessed 16. Apr 2016).

World Health Organization. „Global Status Report on Road Safety 2013: Supporting a Decade of Action.“ *World Health Organization.* 2013. http://www.who.int/violence_injury_prevention/road_safety_status/2013/en/ index.html (Accessed 05. Feb 2015).

Zhang, Wenwen, Subhrajit Guhathakurta, Jinqi Fang, and Ge Zhang. „Exploring the impact of shared autonomous vehicles on urbanparking demand: An agent-based simulation approach .“ *Sustainable Cities and Society* 19 (2015): 34–45 .

Zimmer, Johannes, and Bianca Pripfl. *Schneller ans Ziel: Taxi-Apps im Vergleich.* 29. Aug 2014. http://futurezone.at/apps/schneller-ans-ziel-taxi-apps-im-vergleich/82.245.170 (Accessed 21. Apr 2016).

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Appendices

Appendix 1:

The European Commission has established and funded a number of research and development projects to support the development of autonomous vehicles and ITS. Figure 16, below, offers a graphical overview of these projects. The red arrows show projects that have been completed; the green arrows indicate projects that were still running when the figure was created (EPoSS 2015).

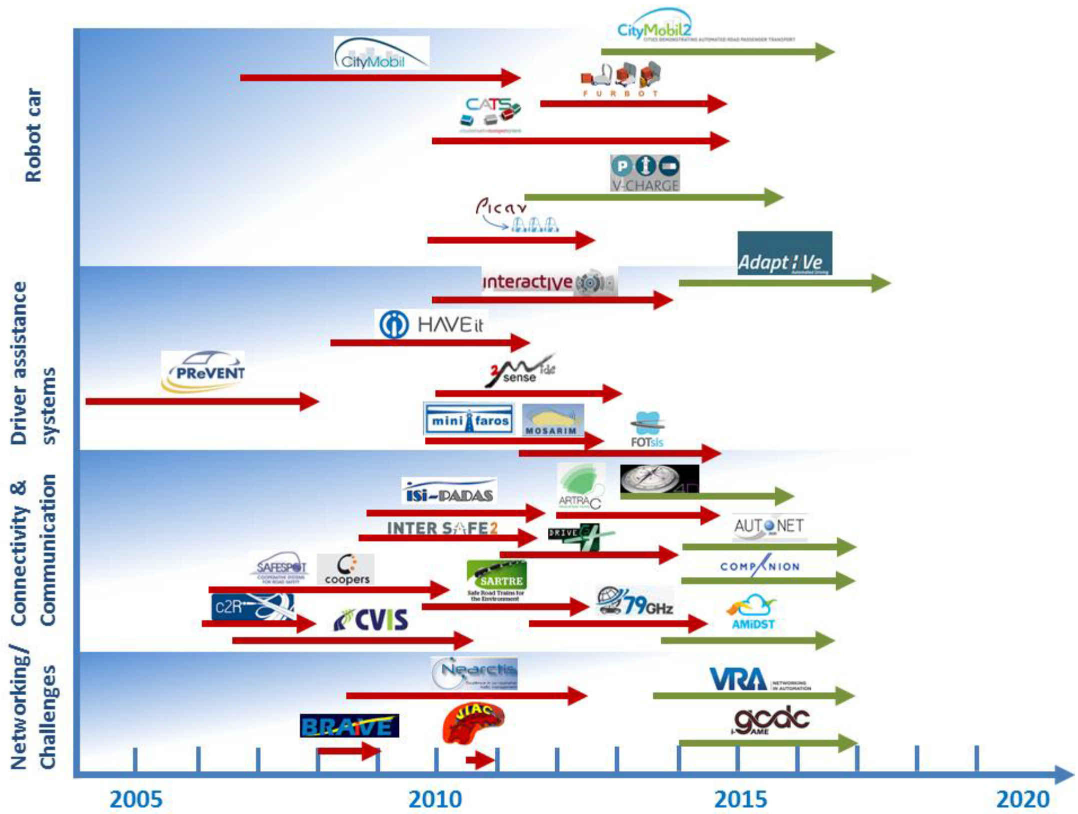

Figure 16: European Commission funded automated driving projects (EPoSS 2015)

Appendix 2:

Herry Consult GmbH (2009) conducted additional surveys in four pre-selected regions. These areas are Southern Mostviertel, Tullnerfeld West, selected parts of the Waldviertel, and Melk (city). The areas included in the four regions are as follows:

- **Melk** (city)
- **Southern Mostviertel**: Waidhofen an der Ybbs (city), Hollenstein an der Ybbs, Opponitz, Sankt Georgen am Reith, Ybbsitz, Göstling an der Ybbs, Lunz am See
- **Tullnerfeld West**: Atzenbrugg, Judenau-Baumgarten, Königstetten, Langenrohr, Michelhausen, Muckendorf-Wipfing, Sieghartskirchen, Sitzenberg-Reidling, Tulbing, Tulln an der Donau, Würmla, Zwentendorf an der Donau
- **Regions in Waldviertel**: Eggern, Eisgarn, Haugschlag, Heidenreichstein, Litschau, Reingers, Bad Großpertholz, Großschönau, Moorbad Harbach, Sankt Martin, Weitra, Unserfrau-Altweitra, Dietmanns, Dobersberg, Gastern, Groß-Siegharts, Karlstein an der Thaya, Kautzen, Ludweis-Aigen, Pfaffenschlag bei Waidhofen a.d.Thaya, Raabs an der Thaya, Thaya, Waidhofen an der Thaya, Waidhofen an der Thaya-Land, Vitis, Waldkirchen an der Thaya, Windigsteig, Allentsteig, Schwarzenau, Echsenbach, Göpfritz an der Wild