D2.1 Literature review on the acceptance and road safety, ethical, legal, social and economic implications of automated vehicles

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BRAVE

BRidging gaps for the adoption of Automated VEhicles

No 723021

D2.1 Literature review on the acceptance and road safety, ethical, legal, social and economic implications of automated vehicles

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Deliverable nature:	Report (R)
Dissemination level: (Confidentiality)	Public (PU)
Contractual delivery date:	30 November 2017
Actual delivery date:	30 November 2017
Version:	V1.0
Total number of pages:	76
Keywords:	Automated driving, autonomous driving, acceptance, public opinion, organised stakeholders, ethical aspects, legal aspects, social aspects, economic aspects, road safety

Abstract

This deliverable summarizes the findings of an extensive literature review on the acceptance, behavioural intentions, road safety, as well as ethical, legal, social (ELSI) and economic considerations in the scope of vehicle automation.

The theoretical fundaments and relevant findings of recent public opinion research regarding user acceptance of automation are presented. Also the view of organised stakeholders is taken into account.

Regarding road safety there is a potential for increased road safety but drivers tend to pick up non-related driving tasks instead. These problems are due to several traditional HMI concerns. In the future autonomous cars must make decisions that touch on ethical issues that have not yet been sufficiently and transparently discussed. Although in many countries legislation is now reacting to the new technology, many aspects – like liability and privacy / data protection – are not yet regulated by law. Automated vehicles promise to have several clear benefits that might change the entire transport system. The positive externalities that come from the technological advantages of automated vehicles might be outweighed by the negative externalities coming from the potential increases in travelling by private vehicles.

Executive summary

BRAVE's approach assumes that the launch of conditionally and highly automated vehicles (SAE automation level 3 and 4) on public roads will only be successful if a user centric approach is used. Therefore, technical innovations have to be developed in compliance with societal values, user acceptance, behavioural intentions, road safety aspects and social, economic, legal and ethical considerations.

This report provides a brief overview on definitions and theoretical approaches to acceptance. There is no universal, valid definition to acceptance nor a single approach, but a broad range of theoretical constructs, so that it still is not certain which model fits best with the objectives of BRAVE. Studies of public opinion on acceptance and attitudes on automated driving indicate that fears related to system failure seem to be present in the public and need to be taken into account. The literature review shows that the general level of trust in automated or autonomous driving is limited, within the reviewed studies the majority of participants were concerned that self-driving vehicles cannot drive as well as human drivers. Worries regarding system failure can also be related to trust problems. The comfort that passengers of highly / fully automated vehicles expect or what secondary task they engage in might depend on their tendency to trust machines. Research findings clearly illustrate that males and females have distinct perceptions, expectations and concerns towards automated / autonomous vehicles. The finding of the described surveys suggest that men generally have more positive expectations regarding automated features / driver assistance systems in cars and also seem to be slightly more willing to buy such systems than females and that the attitude of females towards automated / autonomous vehicles is rather reserved. Other implications important for the focus of BRAVE can be related to worries about data privacy and liability. As it is not clear yet who will be liable in what situation and who will have the right to access the data gathered with the introduction of automated driving on European roads, the uncertainty was found to be a concern to European citizens. Research findings also clearly illustrate that males and females have distinct perceptions, expectations and concerns towards automated / autonomous vehicles. Men generally have more positive expectations regarding automated driving and also seem to be slightly more willing to purchase such systems than females and have other ideas regarding how to spend their time within self-driving vehicles. The attitude of females towards automated / autonomous vehicles is rather reserved, females also state to know less about and to be less interested in these types of technical innovations and they express more doubts about the safety of self-driving systems and a higher tendency to mistrust in such systems driving.

Organised stakeholders are, either directly or indirectly, likely to be affected by AVs. It is important to include their perspective so that automated vehicle technology is widely adopted in a safe and effective manner. There are different expectations on automated transport logistics between different stakeholders and different views regarding the timing of widespread implementation and adoption of automated vehicles. A common issue that is addressed concerns legal aspects.

The review of studies concerning human-machine-interaction (HMI), transfer of control (TOC), mental workload (MWL), situational Awareness (SA) and trust indicates that cars on SAE level 2 and level 3 of automation are shadowed by several issues that are problematic from a road safety perspective. Studies show that humans are not well suited for supervision tasks and therefore easily lose track of the situation at hand and intervene less well compared to being in control at all times. The road safety literature suggests a problematic pattern of issues. These concerns or issues will need to be considered if potential increases in road safety from AV are to be realised. There is a potential for improved road safety, as long as driver behavioural adaptation – such as drivers engaging in non-related driving tasks – can be mitigated.

There has been a discussion about the ethical implications of autonomous driving for some years now, mainly about ethical issues in unavoidable accident situations where at least one road user gets harmed. The literature review only allows limited conclusions, so it cannot be decided what would be the most appropriate ethical approaches for the programming of autonomous cars – there is no consensus on this in the literature – and whether there should be the possibility of individual Personal Ethics Settings (PES) for the users of automated cars. The few empirical studies on how the public thinks about the ethics settings of autonomous cars also show no clear result. There seems to be an acceptance that a car should be programmed in such a way that, in the event of a crash, as little human harm as possible occurs, but it is not clear whether many people would be willing to purchase or use a car, which sacrifices the car occupant to save someone else's life. In the future autonomous cars must make decisions that touch on ethical issues and these ethical issues have not yet been sufficiently and transparently discussed in the public. Such a discussion would be

important because rules have to be drawn up here, which have to balance between the two socially important ethical principles of self-determination and safety. And the way automated / autonomous vehicles are ethically programmed will also determine their societal acceptance.

The brief overview of the legal implications of autonomous cars shows that in many countries legislation is now reacting to the new technology. Nevertheless, many aspects and topics are not yet regulated by law; at least this could be the impression for the legal layman. The issues of liability – who is liable in which case for a crash – and privacy – who has access to the data collected by the automated car – should be regulated comprehensibly and transparent for the ordinary consumer in order to make the market launch of automated cars a success.

Regarding the social and economic impacts, many studies predict that on the one hand the deployment of automated cars will have the potential to reduce crashes, increase fuel efficiency, reduce parking demand, improve road capacity, ease congestion, and increase mobility for non-drivers. On the other hand there could be negative externalities such as increased congestion and environmental degradation and negative effects on employment. The great uncertainty regarding how people will change their travel behaviour makes it hard to draw any clear conclusions regarding the social and economic impacts of automated vehicles. Thus, it is important to further investigate the possible behavioural changes that might come from the implementation of autonomous vehicles, since they will play an important role for the societal acceptance of automated vehicles.

In order to investigate the acceptance of the European population regarding automated vehicles referring to level 3 of vehicle automation, a stakeholder survey and a representative public opinion survey will be performed within WP2 of BRAVE. To reach a high level of acceptance in the public, it can be assumed that further research is required in order to learn more about the expectations and concerns of European citizens. Within the planned survey, the gender perspective should be included and questions about the ethical preferences of the population should also be asked. This survey could be based on existing acceptance models as described in this report.

Document Information

IST Project Number	723021	**Acronym**	BRAVE
Full Title	BRidging gaps for the adoption of Automated VEhicles		
Project URL	www.brave-project.eu		
EU Project Officer	Georgios Charalampou		

Deliverable	**Number**	D2.1	**Title**	Report on literature review
Work Package	**Number**	WP2	**Title**	Multidisciplinary study and specification of the road users and stakeholders requirements

Date of Delivery	**Contractual**	M06	**Actual**	M06
Status	version 1.0		final X	
Nature	report X demonstrator □ other □			
Dissemination level	public X restricted □			

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Abstract (for dissemination)	This deliverable summarizes the findings of an extensive literature review on the acceptance, behavioural intentions, road safety, as well as ethical, legal, social (ELSI) and economic considerations in the scope of vehicle automation. The theoretical fundaments and relevant findings of recent public opinion research regarding user acceptance of automation are presented. Also the view of organised stakeholders is taken into account. Autonomous cars on the SAE level 2 and level 3 of automation are overshadowed by several issues that are problematic from a road safety perspective. In the future autonomous cars must make decisions that touch on ethical issues that have not yet been sufficiently and transparently discussed. Although in many countries legislation is now reacting to the new technology, many aspects – like liability and privacy / data protection – are not yet regulated by law. Automated vehicles promise to have several clear benefits that might change the entire transport system. The positive externalities that come from the technological advantages of automated vehicles might be outweighed by the negative externalities coming from the potential increases in travelling by private vehicles.
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Version Log			
Issue Date	**Rev. No.**	**Author**	**Change**
15.11.2017	V0.1	Annika Johnsen (IfeS), Niklas Strand (VTI), Jan Andersson (VTI), Christopher Patten (VTI) Clemens Kraetsch (IfeS), Johanna Takman (VTI)	First draft
16.11.2017	V0.2	David P. Pancho (TREE)	First revision of the document
22.11.2017	V0.3	David P. Pancho (TREE)	Detailed revision of the document
29.11.2017	V1.0	Annika Johnsen (IfeS), Niklas Strand (VTI), Jan Andersson (VTI), Christopher Patten (VTI) Clemens Kraetsch (IfeS), Johanna Takman (VTI)	Final version

Responsible authors	
Name and Organisation	**Chapter**
Annika Johnsen (IfeS)	2.1 The acceptance of automated vehicles in the perspective of road users
Niklas Strand (VTI)	2.2 The acceptance of automated vehicles in the perspective of organised stakeholders
Jan Andersson (VTI) Christopher Patten (VTI)	3 Road safety implications of the implementation of automated vehicles in real-life traffic
Clemens Kraetsch (IfeS)	4 Ethical implications of the introduction of automated vehicles 5 Legal implications of the introduction of automated vehicles
Johanna Takman (VTI)	6 Social and economic implications of automated vehicles

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Abbreviations

ACC	Adaptive Cruise Control
ADAS	Advanced Driver Assistance System
AICC	Autonomous Intelligent Cruise Control
AV(s)	Automated / Autonomous Vehicle(s)
BRAVE	BRidging gaps for the adoption of Automated Vehicles
cf.	confer
C-ITS	Cooperative Intelligent Transport Systems
C-TAM-TPB	Combined model of TAM and TPB
D	Deliverable
DAS	driver assistance system
DBQ	Driver behaviour questionnaire
DoA	description of action
DOMA®	Literature database “Machinery and Plants”
EC	European Commission
ELSA	Ethical, legal and social aspects
ELSI	Ethical, legal and social implications
ERTRAC	European Road Transport Research Advisory Council
EU	European Union
e.g.	exempli grata / for instance
et al.	et alii / and others
etc.	Et cetera / and so on
HAD	Highly automated driving
HMI	Human Machine Interface
IDT	Innovation Diffusion Theory
i.e.	id est / that is to say
IfeS	Institut für empirische Soziologie an der Friedrich-Alexander-Universität Erlangen-Nürnberg
ITS	Intelligent Transport Systems
LK	Lane keeping
MADAS	Model of Acceptance of Driver Assistance Systems
MES	Mandatory ethics setting
ML	Machine learning
MPCU	Model of PC Utilization
N	number of participants
p /pp	page / pages
PES	Personal ethics setting
PRM	Persons with reduced mobility

SA	Situation awareness
SAE	Society of Automotive Engineers
SASPENCE	Safe Speed and Safe Distance, an EU-project, subproject to PReVENT, carried out between 2004 and 2007
SCT	Social Cognition Theory
SoA	State of the Art
T	Task
TAM	technology acceptance model
TEMA®	Literature database “Technology and Management”
THW	Time headway
TPB	theory of planned behaviour
TRA	theory of reasoned action
TRID	Transport Research International Documentation
TOC	Transfer of control
TTC	Time to collision
UTAUT	Unified theory of acceptance and use of technology
V2I	vehicle to infrastructure
V2V	vehicle to vehicle
VOT	value of travel time losses
VRU(s)	Vulnerable Road User(s)
WP	work package

1 Introduction[1]

In recent years there has been a rapid technological progress in the development of Advanced Driver Assistance Systems (ADAS). Conditionally and highly automated cars (SAE levels 3 and 4) are about to be launched on the market. These new types of vehicles are expected to improve safety, efficiency, sustainability and comfort. However, automated or autonomous cars bring new technical and non-technical challenges that have to be addressed to ensure safe adoption these new types of cars. In order to meet these challenges, the multidisciplinary BRAVE project was launched as part of the Horizon 2020 European Union research programme.

BRAVE intends to support a fast introduction of automated driving by assuring the acceptance of all relevant users, other road users affected and organised stakeholders. BRAVE's approach assumes that the launch of automated vehicles on public roads will only be successful if a user centric approach is used where the technical aspects go hand in hand in compliance with societal values, user acceptance, behavioural intentions, road safety, ethical, legal, social (ELSI) and economic considerations.

The present Deliverable D2.1 summarises the findings of an extensive literature review exploring and documenting the acceptance of vehicle automation on the side of the road users and on the side of organised stakeholders. Various ethical, legal, and social aspects as well as road safety and economic implications are reviewed. On one hand this literature review will serve as the basis for the development of adequate survey questions that will be applied in the BRAVE survey of organised stakeholders (T2.3) and the BRAVE survey of ordinary road users (T2.4). On the other hand this review can serve as a guide for the technical development of automated cars (WP3 and WP4). Last but not least it provides the interested public with basic knowledge regarding societal, road safety, ELSI and economic aspects of the user-centric approach of BRAVE.

Chapter 2 is based on the construct of acceptance and provides relevant definitions (cf. section 2.1.1) as well as theoretical fundaments of the acceptance of technology, particularly advanced driver assistance systems and self-driving vehicle technology (cf. section 2.1.2). Subsequently, results of recent public opinion research are presented and discussed in the light of their meaning for BRAVE (cf. section 2.1.3). Section 2.2 describes the results of scientific studies on the acceptance of automated vehicles by organised stakeholders (cf. section 2.2.1) and presents stakeholder organisations' position papers (cf. section 2.2.2).

Studies dealing with road safety aspects of automated cars are presented and discussed in chapter 3. Therefore, studies on the topics transfer of control / levels of control (cf. section 3.1), feedback, mental workload, SA and trust (cf. section 3.2), accidents and failures (systems) (cf. section 3.3), driver and infrastructure condition (cf. section 3.4), additional effects and modelling (cf. section 3.5), influence on non-AV drivers (cf. section 3.6) and methodology / technical development (cf. section 3.7) are reviewed.

Chapter 4 is about the ethical implications of autonomous cars. For this purpose, the discussions held in the ethical literature on the following topics are outlined: Should non-automated driving be prohibited in the future (cf. section 4.1)? How should a self-driving car be programmed and behave in case of an unavoidable crash (cf. section 4.2)? Who should decide about the ethical principles that automated cars follow (cf. section 4.3)? Furthermore, the results of studies and surveys on the ethical attitudes of their participants are presented (cf. section 4.4).

Chapter 5 discusses the legal implications of automated driving, which are likely to be relevant for future users. To this end, it is briefly discussed to what extent conditionally and highly automated and autonomous cars are permitted by law in the participating countries of BRAVE (cf. section 5.1.1), which issues arise with regard to liability – in the event of a crash – (cf. section 5.1.2) and privacy (cf. section 5.2).

The social and economic implications of automated driving are discussed in chapter 6. The potential effects on the following subjects are described: Car sharing (cf. section 6.1), equality in the transport system (cf. section 6.2), travel behaviour (cf. section 6.3), safety (cf. section 6.4), efficiency (cf. section 6.5), congestion

[1] In this report, the terms "autonomous" car / vehicle and "automated" car / vehicle are used interchangeably, even if they do not have the same meaning in a narrower sense (there are different levels of automation, a fully automated car would be an autonomous car). In the individual parts of the report, if necessary, a reference is made to the type / level of automated car currently being under discussion.

(cf. section 6.6), environment (cf. section 6.7), parking (cf. section 6.8), public transit (cf. section 6.9), employment (cf. section 6.10) and public opinion on social and economic impacts (cf. section 6.11).

Chapter 7 contains the summaries and conclusions of each chapter.

2 Acceptance of automated vehicles

2.1 The acceptance of automated vehicles in the perspective of road users

Acceptance appears to be the core-element of WP2 within the project BRAVE. In this context it was emphasized that “the launch of automated vehicles on public roads will only be successful if a user centric approach is used where the technical aspects go hand in hand in compliance with societal values, user acceptance, behavioural intentions, road, safety, social, economic, legal and ethical considerations” (EC-INEA, 2017, p. 10). Acceptance by the public is a precondition for the deployment of new in-vehicle technology. “It is unproductive to invest effort in designing and building an intelligent co-driver if the system is never switched on, or even disabled” (Van der Laan, Heino, de Waard, 1996, p. 1).

2.1.1 Definitions

User acceptance is a prerequisite for the successful introduction of autonomous driving to the European market. In general, the term of acceptance is referred to the process of agreeing, approving, or acknowledging someone / something, whilst also including an active component described as “willingness for something” (Fraedrich & Lenz, 2016, p. 622). In the context of navigation systems, Franken (2007) refers to user acceptance as “a positive attitude on the part of a user or decision-maker towards accepting a thing or situation” (Franken, 2007, p. 3) and states that the term acceptance assumes a positive attitude regarding a certain circumstance. He divides acceptance into attitudinal and behavioural components, stating that attitudinal acceptance combines emotions as well as experience, whilst behavioural acceptance refers to a form of observable behaviour (cf. Franken, 2007). In the context of driver assistance systems (DAS), Adell (2009) gives a more specific definition referring to acceptance of driver assistance systems as “the degree to which an individual intends to use a system and, when available, to incorporate the system in his/her driving” (Adell, 2009, p. 31). As SAE J3016 level 3 (cf. SAE, 2016) of vehicle automation is not available to the population on the market at present (October 2017), research on direct behaviour (assuming behavioural acceptance) is not provided within the present literature review. Therefore, the focus will be set on behavioural intentions (intention to purchase, willingness to pay, intention to use).[2]

2.1.2 Theoretical fundaments of acceptance

To explain factors having an impact on the acceptance of automated vehicles various theoretical models, e.g. stemming from research in the acceptance of information technology, are applicable (cf. Venkatesh, Morris, Davis, & Davis 2003, pp. 428 for an overview). These models are derived from the theory of planned behaviour, an approach that explains human behaviour on the basis of a person’s perceptions and appraisal of situational factors, social influence and his / her own value system (cf. Ajzen, 1991). In the following section the relevant acceptance models, referring to technology acceptance (cf. Davis, 1989), acceptance of driver assistance systems (cf. Arndt & Engeln, 2008; Arndt, 2011) and acceptance of driverless vehicle technology (cf. Kelkel, 2015), all derived from a common underlying theoretical concept, will be described and discussed. This forms the basis on which the further findings on the acceptance of (semi-)autonomous vehicles within the general population / public will be discussed afterwards.

[2] The following databases were used for the literature review on user acceptance and public opinion: TRID, Scopus, PsycINFO, PSYNDEX and Elsevier / ScienceDirect. Search words were “automated car”, “self-driving car”, and “autonomous car” / “vehicle”, in combination with “acceptance” or “public opinion” or “survey”. In the numerous articles (some of which were not peer-reviewed) dealing with the acceptance of automated / autonomous vehicles in greater detail, the lists of references were used to find more literature. Furthermore, the Internet was searched for surveys on the attitudes of road users regarding automated and autonomous driving. Not all relevant publications can be considered in this review. A subjective selection was made on the basis of the structured aggregated information from the individual sources.

2.1.2.1 Theory of reasoned action and theory of planned behaviour

An important contribution to describe the link between beliefs and behaviours is provided by the theory of planned behaviour, briefly TPB (Ajzen, 1991). The TPB was preceded by the theory of reasoned action (TRA) of Fishbein and Ajzen (1975), one of the most fundamental and influential theories to predict human behaviour (cf. Kelkel, 2015, p. 16). The TRA posits that a person's behaviour is influenced by his / her behavioural intention. The behavioural intention emerges from personal attitudes, as well as subjective norms referring to the respective behaviour (cf. Fishbein & Ajzen, 1975 cited in Kelkel, 2015, p. 16). According to Ajzen (1991), the attitude towards a behaviour is defined as "the degree to which a person has a favourable or unfavourable evaluation or appraisal of the behaviour in question", whilst the subjective norm can be referred to as "the perceived social pressure to perform or not to perform the behaviour"(Ajzen, 1991, p. 188).

The TRA by Fishbein and Ajzen (1975) was revised in 1991 by Ajzen. The revised model (TPB) included a third variable of influence – the perceived behavioural control described as "perceived ease or difficulty of performing a behaviour" (Ajzen, 1991, p. 188). This extension of the TRA was necessary to account for non-voluntary behaviours (cf. Kelkel, 2015). The interrelations between the described factors are depicted in Figure 1.

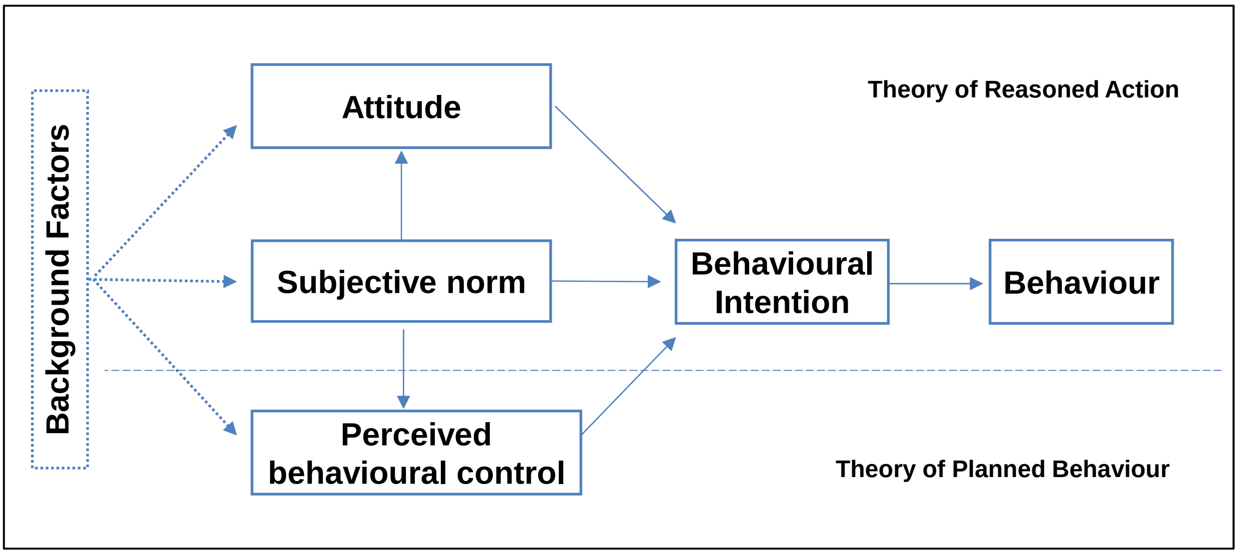

Figure 1: Theory of reasoned action and theory of planned behaviour
(Source: Kelkel, 2015, p. 17)

2.1.2.2 Technology Acceptance Model

A more technical approach to acceptance was given by Davis (1989). His Technology Acceptance Model (TAM) was developed on the basis of the theory of reasoned action by Fishbein and Ajzen (1975) and provides an explanative approach why an individual adopts or rejects the use of a technical system. The TAM posits that the attitude to use a new technology is influenced by "the degree to which a person believes that using a particular system would enhance his or her job performance" (perceived usefulness) and "the degree to which a person believes that using a particular system would be free of effort" (ease of use) (Davis, 1989, p. 320). This means that the attitude of an individual towards using a technical system becomes more positive the more he or she perceives it as useful and thinks it can be easily used. This results in the individual being more likely to use the system (cf. Davis, 1989; Davis, Bagozzi, & Warshaw, 1989; Jokisch, 2009). The model was found to predict approximately 40 % of system use (Davis et al., 1989).

In later versions of TAM the attitude toward using a technology is often neglected whilst the perceived usefulness and the perceived ease of use are assumed to directly influence the behavioural intention and thereby the use of the system (cf. Venkatesh & Davis, 2000). As can be seen in Figure 2, the original version of TAM posits that the perceived usefulness as well as the perceived ease of use are influenced by further external variables. Whilst in the original version of TAM these variables were not specified yet, Jokisch (2009) divides them into variables referring to social processes (voluntariness of use, subjective norm, and system image) and variables referring to cognitive-instrumental processes (systematic importance, quality of results, and perceptibility of results) within the model extension TAM2 (cf. Venkatesh & Davis, 2000). In the further development towards TAM2 and TAM3 (cf. Venkatesh & Bala, 2008) especially subjective norm is lifted out and discussed in more detail (cf. Venkatesh & Morris, 2000). The original TAM complemented by subjective norm is displayed in Figure 2.

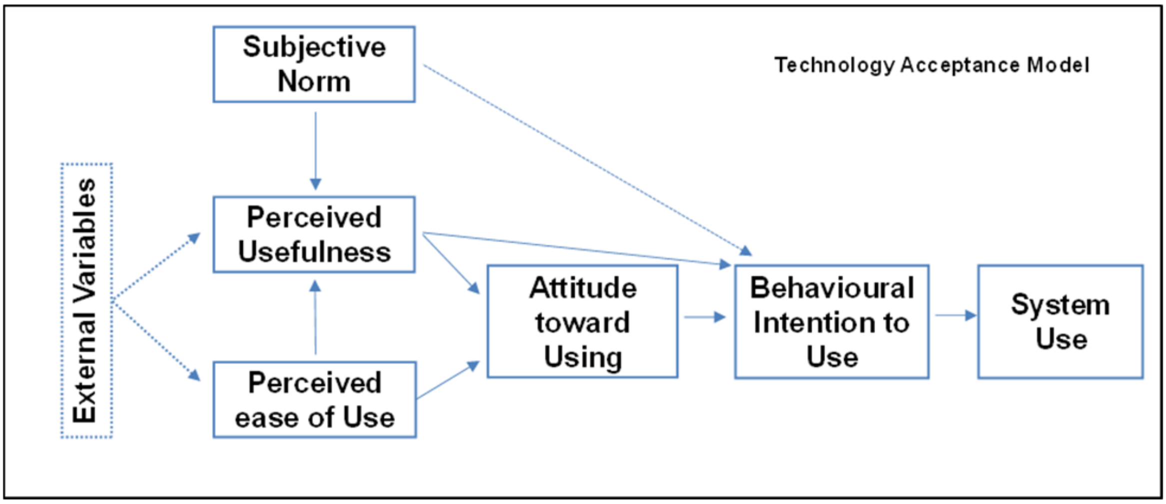

Figure 2: Technology Acceptance Modell
(Source: Based on Davis, 1989; Davis et al. 1989, p. 985; Jokisch, 2009, p. 237; Venkatesh & Morris, 2000, p. 118)

2.1.2.3 Unified Theory of Acceptance and Use of Technology

A further, recent instrument for assessing the acceptance and use of technology is the unified theory of acceptance and use of technology (UTAUT) developed by Venkatesh et al. (2003). This theory was developed in order to describe the acceptance of information technology within organizations. It revises and integrates eight models of individual acceptance, including the theory of reasoned action, the technology acceptance model (TAM), the motivational model, the theory of planned behaviour (TPB), a combined model of TAM and TPB (C-TAM-TPB), the model of PC utilization (MPCU), the innovation diffusion theory (IDT) and the social cognitive theory (SCT) (for references see Venkatesh et al., 2003, p. 425). As can be seen in Figure 3, UTAUT explains intentions to use an information system and subsequent usage behaviour by the four key determinants performance expectancy, effort expectancy, social influence and facilitating conditions. It is thereby posited that the intention to use a system is influenced by performance expectancy, effort expectancy and social influence (cf. Venkatesh et al., 2003). Performance expectancy is described as the degree to which an individual believes that using the system will help him or her to attain gains in job performance, whilst effort expectancy refers to the degree of ease associated with the use of the system (cf. Venkatesh et al., 2003). Social influence outlines the degree to which an individual perceives that important others believe he or she should use the new system (cf. Venkatesh et al., 2003, p. 451). Usage behaviour is found to be directly influenced by the intention to use and facilitating conditions, the latter being referred to as the degree to which individuals are aware of organizational and technical infrastructures supporting the use of the system (cf. Venkatesh et al., 2003).

Besides the impact of the described components Venkatesh et al. (2003) also find moderating influences of the variables gender, age, experience and voluntariness of use on the intentional / behavioural variables. All in all, UTAUT is found to outperform the eight stated models of individual acceptance, accounting for 70 % of the variance (adjusted R^2) in use behaviour (Venkatesh et al. 2003, p. 468). The authors consider UTAUT to be a substantial improvement over any of the eight single models tested as well as their extensions.

The assessment of acceptance of technology by UTAUT is also used in areas other than information technology, examples being mobility services and the health sector (cf. Adell, 2009, p.43). An extension of

UTAUT to the context of driver support systems is provided by Adell (2009). The author uses a modified version of the UTAUT questionnaire to assess the acceptance of SASPENCE, a system which assists the driver to keep a safe speed and a safe distance to vehicles ahead (cf. Adell, 2009, p. 45). She shows that performance expectancy and social influence have a significant positive effect on the intention to use SASPENCE, whilst effort expectancy does not affect the intention to use SASPENCE in a significant way.

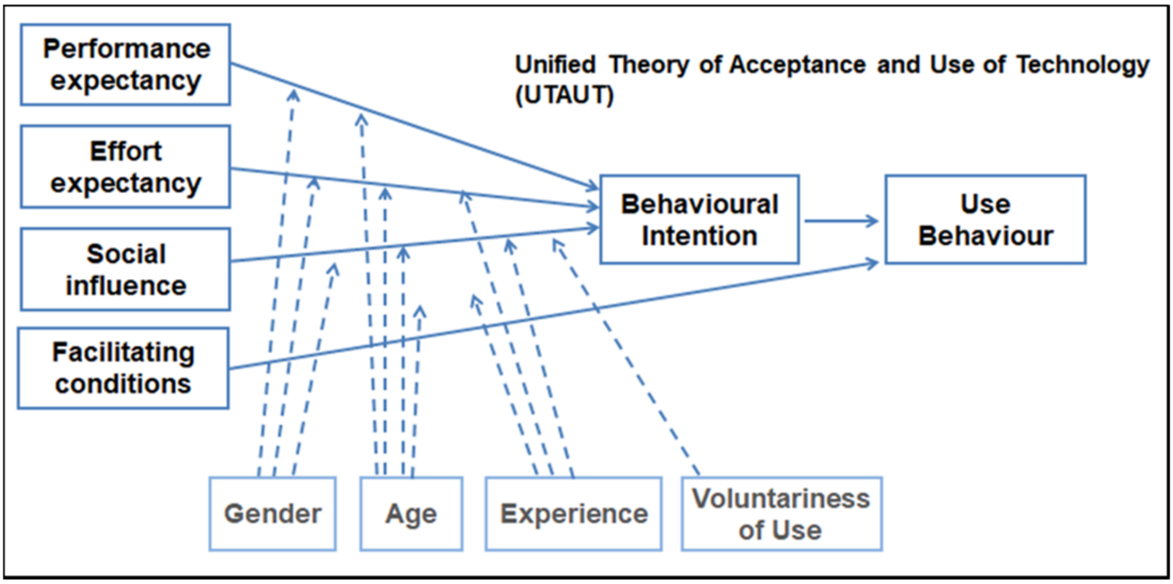

Figure 3: Unified Theory of Acceptance
(Source: Based on Venkatesh et al., 2003, p. 447)

2.1.2.4 Model of Acceptance of Driver Assistance Systems

A model of acceptance directly related to the acceptance of driver assistance systems is the Model of Acceptance of Driver Assistance Systems (MADAS) developed by Arndt & Engeln (2008). It is similar to TAM in being based on TPB (Fishbein & Ajzen, 1975; Ajzen, 1991), but in contrast to TAM also includes components of the acceptance model of road pricing measures (cf. Schlag & Teubel, 1997). MADAS conceives the purchase intention as acceptance, resulting from variables of the TPB being on their part influenced by perceived product features.

The perceived product characteristics summarize characteristics related to the use of DAS and evaluate the degree to which users approve / reject them. In this context it was proposed that the use of DAS has an impact on comfort, driving enjoyment, driving safety, eco-friendliness and driver image. Consequently, MADAS assesses the individual perceptions on all these factors and adds the components consumer’s trust and usability to the construct (cf. Kelkel, 2015, p. 18).

The subjective norm is described as a person’s perception of whether people who are important to him / her think he should or should not perform the behaviour in question (cf. Arndt & Engeln 2008, p. 317). Other than in TPB, in MADAS this component is found to have an indirect impact on purchase intention via attitude toward buying DAS, which refers to consequences / values connected to the idea of buying and using DAS.

The attitude toward buying DAS directly influences the perceived behavioural control and therefore indirectly influences purchase intention (cf. Kelkel, 2015). The perceived behavioural control is described as the ease / difficulty to purchase DAS an individual derives from his / her own abilities, resources and situational factors (cf. Arndt & Engeln 2008, p. 317).

The purchase intention is used synonymously to the behavioural intention by Ajzen (1991) and refers to the degree to which an individual believes that he / she will acquire DAS in the future (cf. Arndt, 2011, p.69). According to the TPB (cf. Ajzen, 1991) behavioural intention appears to be a reliable predictor for the behaviour itself.

MADAS was revised within the doctoral thesis of Arndt (2011), who performs a two-step structural equation model analysis. Arndt (2011) tests the model on a navigation system and reveals that all effects from perceived product characteristics are mediated by the variables of the TPB on purchase intention. The revised model is displayed in Figure 4.

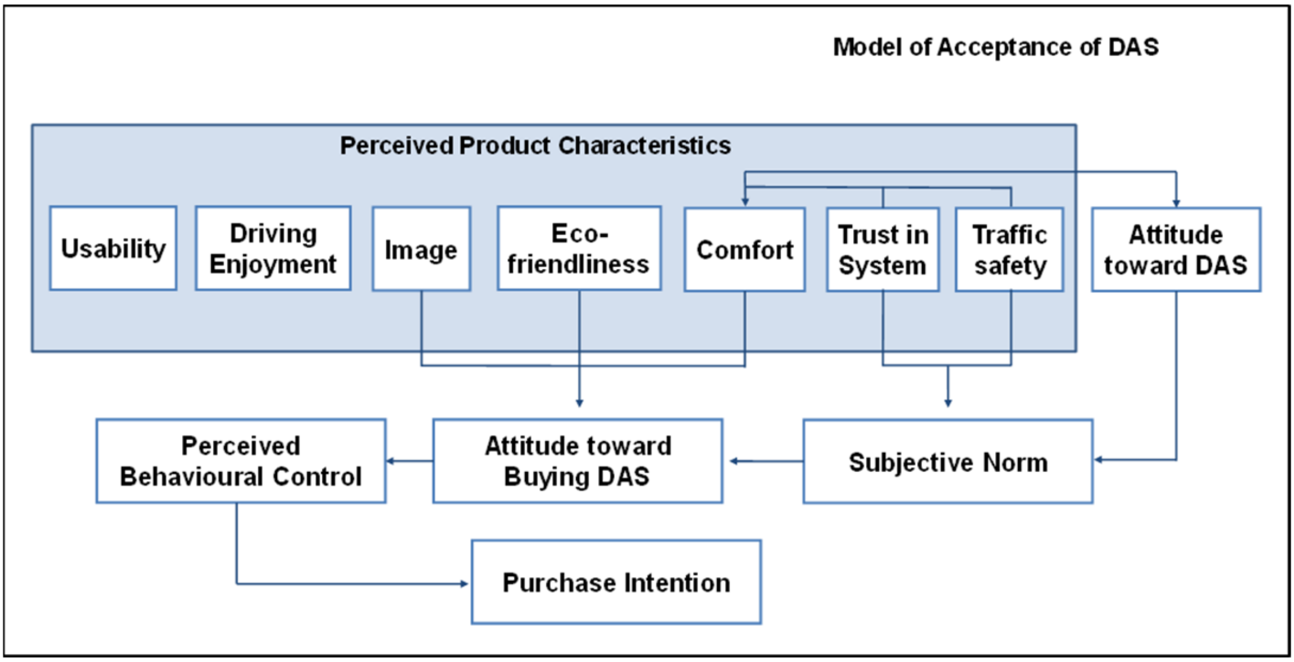

Figure 4: Revised Model of Acceptance of DAS by Arndt
(Source: Adapted from Kelkel, 2015, p. 160)

2.1.2.5 Model of Acceptance of fully autonomous driving systems

A further version of MADAS is proposed by Kelkel (2015), who adapts the model of Arndt (2011) to fully autonomous / driverless systems. Within the new model and on the basis of current literature on driverless systems the variable "usability" is replaced by the factors "time saving", "productivity" and "utilization" (cf. Kelkel, 2015, p. 21). In order to evaluate interrelations between the perceived product characteristics and to investigate whether they predict the consumer's purchase intention via "attitude" and "subjective norm", explorative factor analyses are used. As a result, the variables "trust in system" and "traffic safety" are merged into one single variable named "trust in safety". Similarly, also the variables "utilization", "time saving" and "productivity" are assigned to a new variable named "efficiency". Kelkel (2015) evaluates the impact of these different components on acceptance (purchase intention) by using structural equation modelling. He finds that only the variables from TPB, "attitude towards buying" and "subjective norm", have a direct influence on the intention to purchase driverless / autonomous vehicle technology. Furthermore, he reports attitudes to mediate effects from subjective norm on purchase intention. The perceived product characteristics "efficiency", "trust in safety" and "eco-friendliness" are found to influence the intention to purchase via the behavioural variables of TPB. In this context the attitude is most influenced by "trust in safety", followed by "efficiency", whilst the "subjective norm" is determined by "eco-friendliness", "trust in safety" and "efficiency". The variables "comfort", "image" and "driving enjoyment" have no effect on any of the variables of TPB, neither on purchase intention (see Figure 5).

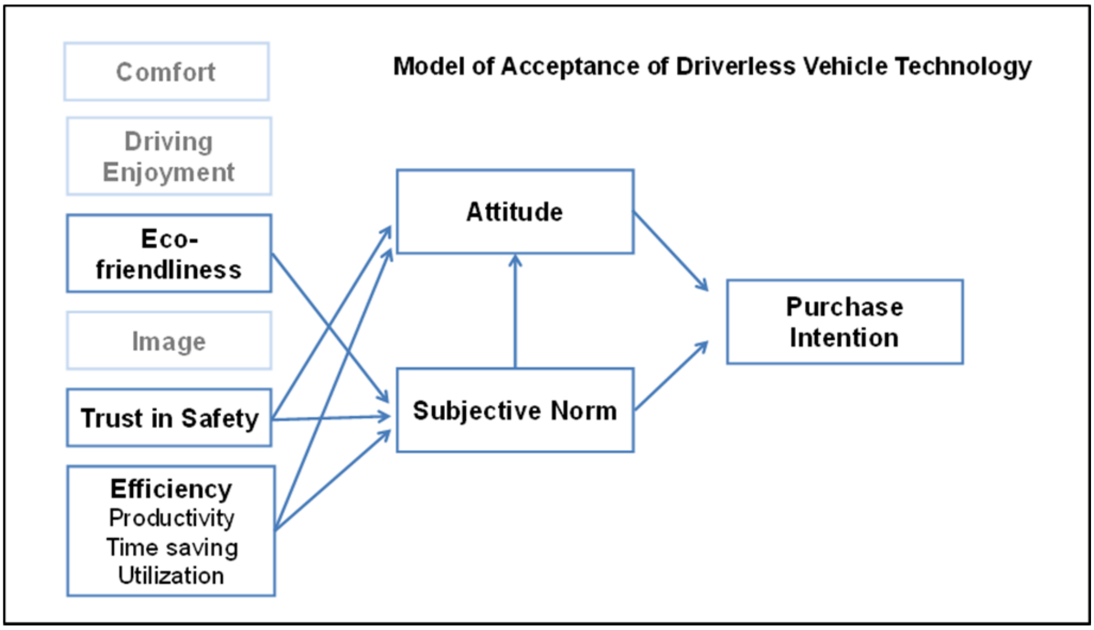

Figure 5: Model of Acceptance of Driverless Vehicle Technology by Kelkel
(Source: Kelkel, 2015, p. 39)

2.1.3 The acceptance of highly and fully automated vehicles within the general population

During the literature review it can be established that current research on public opinion and acceptance of automated vehicles is quite broad and direct links to acceptance models remains vague. This might not least be due to the non-existence of one universal definition of acceptance (cf. Adell, 2009). However and somewhat common to all of the reviewed articles / surveys or studies is the fact that those studies investigated attitudes towards the use of highly automated vehicles (e.g. time savings, driving enjoyment, safety) or / and estimates on legal / social / economic consequences connected to the introduction of highly automated vehicles on public roads. It should be noted here that not all mentioned aspects are included within this chapter. The author of this section rather focussed on common points, i.e. attitudes related to the use of automated vehicles which were found in several articles. Furthermore findings on behavioural intentions (purchase intention, willingness to pay, and intention to use) are deployed to provide general view on the acceptance of automated vehicles from a behavioural perspective.

2.1.3.1 Background of the research on public opinion

The following chapter is based on the findings of ten recent studies on public opinion of automated driving. Three of them are based on attitudes and opinions of German samples (ACV, 2015; Bock, German & Sippl, 2017; Gladbach & Richter, 2016), two others conducted among French samples (Payre, Cestac, & Delhomme, 2014; Piao et al. 2016), whilst the others investigate the attitudes of U.S.-citizens (Schoettle & Sivak, 2014, 2015, 2016), UK-citizens (Schoettle & Sivak, 2014) and Australian citizens (Schoettle & Sivak, 2014). Also the findings of a Slovenian survey (Šinko , 2016) were included. Further findings included within this report are those of the multinational survey of Kyriakidis, Happee and de Winter (2015) and those of a survey conducted by the Observatorio Cetelem Auto of Spain (2016). Details about locations, distribution methods, number of respondents and methodology of each study can be viewed in table 1.

Table 1: Summary of selected studies on public opinion of highly automated / autonomous vehicles among the general population

Authors	Year	Location	Distribution method	N*	Methodology	Automation level	Behavioral intention
ACV	2015	Germany	Online questionnaire	1.021	Descriptive	Autonomous (not classified)	Purchase intention, Intention to use
Bock, German & Sippl	2017	Germany	Online questionnaire	888	Descriptive	Fully automated	Purchase intention
Gladbach & Richter	2016	Germany	Online questionnaires	663	Descriptive	Autonomous (According to SAE standard, not classified).	Purchase intention, Intention to use
Kyriakidis, Happee, & de Winter	2015	109 countries	Online questionnaire	4.886	Descriptive	BASt	Purchase intention
Observatorio Cetelem	2016	15 countries	Online questionnaire	8.500	Descriptive	Autonomous vehicles	Intention to use,
Payre et al.	2014	France	Interviews, online questionnaire	421	Descriptive, Inferential	Conditionally or highly automated	Purchase intention
Piao et al.	2016	France	online questionnaire, telephone interview	425	Descriptive	Automated vehicles (not classified)	Intention to use
Schoettle & Sivak	2014	US, UK, Australia	Online questionnaire	1.533	Descriptive, Inferential	NHTSA	Purchase intention
Schoettle & Sivak	2016	US	Online questionnaire	618	Descriptive	Partially, highly and fully automated driving	N / A
Šinko	2016	Slovenia	Online questionnaire	549	Descriptive	Autonomous vehicles	Purchase intention

2.1.3.2 Perceptions related to product characteristics and consequences of using highly automated vehicles

The following section contains results of the reviewed studies related to attitudes of potential users towards the use of highly automated vehicles (HAV). The public opinion surveys often related to factors that could discourage potential users from using or purchasing highly automated vehicles (barriers) or factors rendering their use even more appealing (enablers). The relevant findings on aspects that were contained within the studies several times are described below.

2.1.3.2.1 Safety

The safety of automated driving vehicles is an implication that is strongly perceived by the public. In the survey of Observatorio Cetelem (2016) it was rated as main priority for the introduction of "connected vehicles"[3] by most of the participants (77 %) followed by cost (73 %) and time savings (50 %) (cf.

[3] It was not clear on what basis the Spanish source distinguished connected vehicles and autonomous vehicles or whether the two terms are used synonymously.

Observatorio Cetelem Auto, 2016, p. 53). Questions on safety aspects were contained by nearly all the reviewed studies. The perception of safety in highly automated vehicles seems to be a rather complicated issue. Within the described surveys safety is either brought up as barrier or enabler of acceptance. Safety benefits of automated vehicles are often referred to the crash reduction potential of highly automated vehicles. As most crashes (90 %) are due to human error, reckless driving or driving under the influence of drugs, alcohol or medicines (cf. Fagnant & Kockelmann, 2015), highly automated vehicles bear the potential of reducing or even eliminating crashes related to human error. Within the described studies safety benefits as enablers of acceptance are mostly related to a supposed crash reduction or the possibility to eliminate human errors. A question within the survey of ACV (2015) referring to possible advantages of autonomous driving also contains items on safety benefits. In this context 42 % of the participants associate the use of AVs with the reduction of crashes whilst 34 % of the participants believe that self-driving vehicles could increase road safety (ACV, 2015, p. 8). Also in the survey of Piao et al. (2016) 82 % of the participants indicate that safety benefits (linked to the elimination of human errors) are an attribute they consider moderately / very attractive in vehicle automation technology (cf. Piao et al., 2016, p. 2175). So did 77 % of the international survey by Observatorio Cetelem (2016) who moderately / strongly agreed that “connected vehicles are a strong progress in terms of security”. In this context, especially the Spanish participants (81 %) displayed positive expectations regarding safety benefits (Observatorio Cetelem, 2016, p. 50). Also the participants of the survey by Schoettle and Sivak (2014) were rather optimistic about potential safety benefits of self-driving vehicles. In this context the majority believes that the use of self-driving vehicles could result in fewer crashes (70 %) or reduce the severity of crashes (72 %). Declines in crashes in the context of self-driving vehicles are also expected by the majority (79 %) of the respondents in the study of Bock, German, and Sippl (2017, p. 544).

Barriers towards safety are brought up in the context of technical / system failure or the safety and reliability of highly automated vehicles in general. In the survey of Kyriakidis, Happee, and de Winter (2015, p. 133) the majority (65 %) of the participants indicate to be worried about the safety and reliability of fully automated driving systems. Also the majority of the respondents (81 %) of the survey of Schoettle and Sivak (2014) indicate to be moderately or very concerned about safety consequences related to equipment failure or system failure (p. 14). Within the survey of ACV (2015) more than half of the participants (58 %) state reservations about the idea of fully automated driving because they were afraid of technical failure (ACV, 2015, p. 11).

2.1.3.2.2 Data protection

The constant gathering and exchange of data requires special technical and legal measures in order to make sure that the data is not viewed by other parties without the user / driver consenting. Within the survey of Schoettle and Sivak (2014) the majority of the participants (64.5 %) indicate to be moderately / very concerned about the data privacy of self-driving vehicles (cf. Schoettle & Sivak, 2014, p. 14). A similar tendency is found within the ACV-study (2015), where only 35 % of the participants are optimistic about data transmission between self-driving and other actors whilst the majority (48 %) refuses to share their data – thereof 28 % as a matter of principle and 20 % because they are afraid of their data being accessed by third parties, such as their employer or insurance companies (ACV, 2015, p. 10). In the survey of Kyriakidis, Happee, and de Winter (2015, p. 133) it becomes more clear that participants rate data transmission more critical depending on who would be able to access the data. The participants could indicate the degree to which they agree with statements on data transmission on the basis of a 5-point-scale. It is found that participants are rather comfortable with their data being transmitted to surrounding vehicles (Mean = 3.75)[4], vehicle developers (Mean = 3.56) and organisations involved in the maintenance the roadway (Mean = 3.61). They are slightly less comfortable with the scenario of the data being transmitted to insurance companies (Mean = 3.27) or tax authorities (Mean = 2.88).

[4] Mean value on a 5-point scale from 1 = “disagree strongly” to 5 = “agree strongly”.

2.1.3.2.3 Cyber-security

Cyber-security is an implication for automated vehicles of which the real impact on individual safety and society is still unclear. However the risk of hacking reportedly is an object of public concern. In this context, 31 % of participants of the ACV-study (2015) state restraints towards the idea of fully automated driving because of the risk of hacking (not further specified) (ACV, 2015, p. 11). Also in the study of Gladbach and Richter (2016) 56 % of the questioned sample indicates that the risk of hacking dissuades them from wanting to use autonomous vehicles. Further 63 % indicate to be afraid that cyber criminals could take control of autonomous vehicles (cf. Gladbach & Richter, 2016, p. 16). Cyber-security is also addressed in the survey of Schoettle and Sivak (2014). There the respondents state to be moderately or very concerned about the system (69 %) or the vehicle (68 %) being hacked (cf. Schoettle & Sivak, 2014, p. 14).

2.1.3.2.4 Liability

Legal issues are an important matter that can also affect the success of introducing vehicles with higher automation levels on European roads. Liability is addressed within four of the above stated studies. It is shown that the majority of the participants of the (French) sample of Piao et al. (2016) (84 %) are moderately or very concerned about “legal liability in case of an accident” (cf. Piao et al., 2016, p. 2175). Within the study of Kyriakidis, Happee, and de Winter (2015, p. 133) 68 % of the respondents indicate to be worried about the introduction of fully automated driving systems because of the question of who will be legally responsible if a crash occurs. Liability is also an issue of concern in the survey of Schoettle and Sivak (2014) in which the majority of the respondents (74 %) are moderately or very concerned about the legal liability of drivers / owners of self-driving vehicles (cf. Schoettle & Sivak, 2014, p. 14). The reportedly high concern about liability seems somehow opposed to the results of the ACV-study (2015), where only 37 % of the participants state concerns about legal issues (such as liability) in the context of autonomous driving (ACV, 2015, p. 11).

2.1.3.2.5 Joy of driving

The higher the level of vehicle automation the more the driving task is shifted from the driver to the system. Public opinion research shows that this is not always perceived as a benefit. Even though Kelkel (2015) finds no significant effect of driving enjoyment on the intention to purchase within his model of acceptance of driverless vehicle technology, the loss of the joy of driving still seems to be of concern to a relevant share of drivers. At least this is reported by two of the above-stated studies. In this context the survey of ACV (2015) reveals that almost half of the participants (42 %) indicate reservations against fully automated driving because of the loss of driving enjoyment (ACV, 2015, p. 11). According to the study of Kyriakidis, Happee, and de Winter (2015, p. 133) 63 % of the participants are worried that due to the introduction of fully automated driving systems drivers might deprive them of driving enjoyment and the feeling of being in control. This can be aligned with their finding that participants on average rate manual driving the most enjoyable mode of driving (Mean = 4.04)[5], followed by partially (Mean = 3.72), highly (Mean = 3.54) and fully automated driving (Mean = 3.49) (cf. Kyriakidis, Happee, & de Winter, 2015, p. 132). Even if the concern of losing the joy of driving is obviously shared by the public, it is suggested by Observatorio Cetelem (2016) that this aspect still might be less important compared to other issues being perceived as barriers to acceptance. In in their survey participants were asked to choose their primary object of concerns related to connected driving. It was found that among six options, the loss of driving enjoyment occupied the fifth place (9 %) (Observatorio Cetelem, 2016, p. 52). As a consequence it can be retained that the joy of driving seems to be an issue perceived by the public, however its impact on acceptance still requires further research.

[5] Mean value on a 5-point scale from 1 = “disagree strongly” to 5 = “agree strongly”.

2.1.3.2.6 Cost reduction

The introduction of automated vehicles bears the potential of reducing cost that also affect the customer. In this context an interview based study of A.T. Kearney (2016) suggests that a reduction of insurance liability and also reduced energy consumption is expected in the course of the introduction of fully automated cars. Expectations and attitudes towards possible cost benefits are also investigated within two of the eight reviewed studies. The participants of the study of Piao et al. (2016) rate cost benefits related to lower insurance rates (92 %) and reduced fuel consumption (93 %) as a moderately / very attractive feature in automated vehicles. Also the majority of the respondents (72 %) in the survey of Schoettle and Sivak (2014) is quite optimistic about fuel savings associated with the use of self-driving vehicles.

2.1.3.2.7 Trust and control

Within the survey of Bock, German, and Sippl (2017) 60 % of the respondents state to have difficulties trusting AVs. Trust is referred to as “the attitude that an agent will help achieve an individual’s goal in a situation characterised by uncertainty and vulnerability” (Lee & See, 2004, p. 51 cited in Beggiato, Pereira, M., Petzoldt, T., & Krems, 2015). The shift from a human to a system-based control of the driving task requires that the system is able to drive at least as good and safe (or better and safer) as a human driver. Trust in the context of highly automated driving can be described as the driver’s belief that the system drives at least as good and safe as a human driver (goal) with the uncertainty / vulnerability of the situation due to the risk that drivers or passengers might get involved in crashes due to poor system performance.

Within the survey of ACV (2015) one question investigates the opinions of the participants about the driving performance of self-driving vehicle technology compared to human driving. It is found that the percentage of the participants (34 %)[6] who believe that self-driving vehicle technology drives better and safer than a human driver is slightly smaller than the percentage of those who believe that humans are the better drivers (39 %). This tendency is confirmed by Schoettle and Sivak (2014) who report that 67 % of their respondents have stated concerns about “self-driving vehicles not driving as well as human drivers” (cf. Schoettle & Sivak, 2014). All in all it can be concluded that the trust in system driving is limited and that at present the general population prefers humans to be in control of the driving task. This is also suggested by Schoettle and Sivak (2016, p. 14) who find that even in completely self-driving vehicles nearly all of the respondents (94.5 %) prefer to have a steering wheel plus accelerator and brake pedals enabling them to take control of the vehicle if desired. Fears of losing the control of the vehicle were also reported for the sample of the Observatorio Cetelem study (2016). When asked to choose their primary object of concerns related to connected driving, the participants (24 %) were most frequently found to cite the vehicle not being under complete human control as their primary concern (ranked 1st before five other options) (cf. Observatorio Cetelem, 2016, p. 52). In the context of trust issues linked to the control switch from human to system control, it was also reported by Šinko (2016) that 46 % of the participants would not purchase autonomous vehicles because they were not ready to give up the control over the car. Further 37 % were convinced that humans “can still react better than computers” (cf. Šinko, 2016, p. 52).

2.1.3.2.8 Time savings

In SAE level 3 vehicle automation the driving task is performed by a system with the driver being free to spend his or her time on activities other than driving, however, being able to respond to a request to intervene. Most of the reviewed surveys focus on the question of how drivers would make use of their travelling time. In this context Gladbach and Richter (2016) find that the majority of the participants in their sample (49 %) would browse the Internet while travelling whilst about a third (30 %) would use their travelling time to work (if the travelling time is counted as working time). The least preferred option of spending time within the German sample is sleeping while travelling (cf. Gladbach & Richter, 2016, p. 21). Preferences on secondary tasks whilst driving with autonomous vehicles were also investigated by Šinko (2016). It was shown that most participants of her Slovenian sample intended to read (19 %) whilst others

[6] The participants could reply “yes”, “no” or “I don’t know”.

(18 %) indicated they wanted to use their mobile phone, whilst others (16 %) indicated they'd simply watch the environment (not specified). Further 15 % intended to relax or sleep whilst 13 % would make use of their time for working. The inclination of the participants to engage in secondary tasks was also investigated in the survey of Kyriakidis, Happee, and de Winter (2015, p. 133).The authors report that a higher level of vehicle automation is associated with an increased likeliness of the participants to engage in secondary tasks (sleeping, listening to music / radio, passengers etc.). Especially within the fully automated driving level a strongly increasing number of participants intend to rest / sleep, to watch movies or to read (cf. Figure 6).

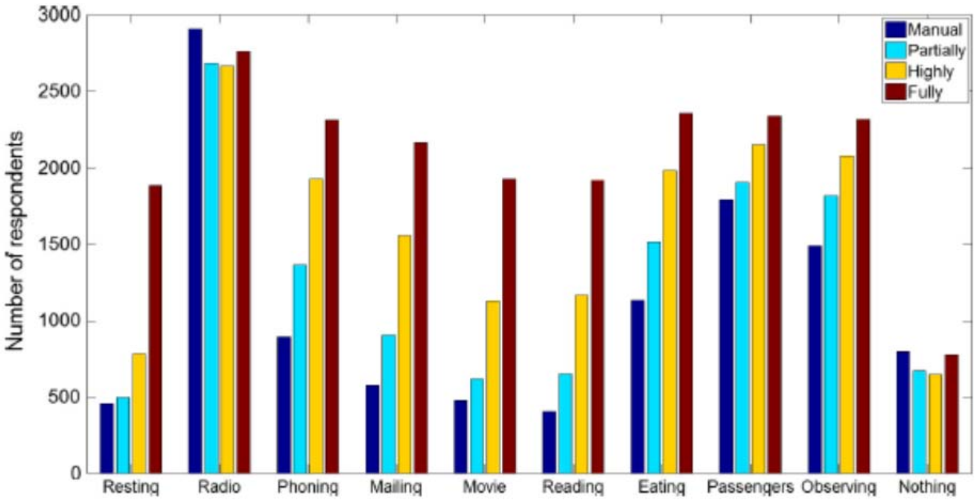

Fig 5. Number of respondents who indicated that they would engage in secondary tasks, for different driving modes (Q59–62). People could select multiple secondary tasks per question in a checkbox question.

Figure 6: Preferred secondary tasks in different levels of automation in the survey of Kyriakidis et al.
(Source: Kyriakidis et al., 2015, p. 135)

This can be traced back to a possible awareness of the participants that such tasks affect the visual attention and / or the level of vigilance. Which secondary task the average person would like to engage in might also depend on trust. This possible connection becomes clear by the findings of Schoettle and Sivak (2014). To the question of "how they would like to spend their time whilst driving in a fully automated vehicle?", the majority of the respondents reply they would "watch the road even though I would not be driving" (41 %), whilst about more than a fifth of the participants (22 %) state they simply would not ride in a completely self-driving vehicle. The remaining 37 % stated reading (8 %), texting or talking with friends (8 %) and sleeping (7 %) as their preferred way of spending time in fully automated vehicles (cf. Schoettle & Sivak, 2014, p. 17).

Within the 15-country-survey of Observatorio Cetelem (2016) the participant's attitudes on spending time were also investigated. It was shown that most of the participants (48 %) stated to prefer spending their time on leisure activities (such as reading, watching movies or browsing the internet), whilst the other participants indicated they would prefer to talk to other passengers (40 %), relax (37 %) or work (25 %). Similar to the findings of Schoettle and Sivak (2014) also here, about every third participant (28 %) indicated the willingness of paying attention to the traffic.

2.1.3.3 Behavioural intentions

According to the different acceptance models described within section 2.1.2 behavioural intentions result from attitudes that can refer to perceptions of specific product characteristics or expectations on efforts linked to the use of a system, its perceived ease of use, social norms related to such systems as well as facilitating conditions / behavioural control. Depending on the respective acceptance model, behavioural intentions can be apprehended in terms of an intention to use (cf. Davis et al., 1989; Venkatesh et al., 2003) or an intention to purchase a specific technology (cf. Arndt, 2011; Kelkel, 2015). The studies relevant for the acceptance of automated driving often measure the purchase intention together with a willingness of the respondents to pay a specific amount. In this manner the value participants assign to such technologies became clear.

2.1.3.3.1 Purchase intention and willingness to pay

Purchase intention regarding fully automated vehicles is relatively low in the German sample of Gladbach and Richter (2016) who report that only a third of the questioned participants indicate an intention to purchase an AV. Within the sample of Bock, German, and Sippl (2017) a rise in price of no higher than €5.000 is acceptable to 43.5 % of the respondents, whilst 41.5 % are not willing to pay more than €1.000. In the study of Payre et al. (2014) the majority of the participants (78 %) state to be willing to buy a fully automated car. The average amount the French respondents are willing to pay is €1.624 (cf. Payre et al., 2014, p. 258). A similar finding is reported by Piao et al. (2016) who state that the majority (73 %) of their French sample would like to own automated cars, whilst 27 % indicate to prefer using them through services such as car sharing, or pooling schemes (cf. Piao et al., 2016). Within the Anglophone sample of Schoettle and Sivak (2014) the degree of interest in having a completely self-driving vehicle as “a vehicle they own or lease” is assessed. It is found that 66 % are very / moderately / slightly interested in possessing this technology. However, the most frequent response to this question is “not at all interested” in each sample of the three countries (UK, U.S. and Australia). Furthermore, it is found that the majority of respondents from all countries are not willing to pay extra for self-driving technology that is 54.5 % of the U.S.-respondents, 60 % of the U.K.-respondents and 55.2 % of the respondents from Australia (cf. Schoettle & Sivak, 2014, p. 17). Kyriakidis, Happee , and de Winter (2015, p. 133) also dedicate three question to the participant’s willingness to pay for technology related to different levels of vehicle automation. It is shown that the respondents are willing to pay the highest amounts of money for fully automated driving (Mean = 4.56)[7], followed by highly automated driving (Mean = 4.28) and partially automated driving (Mean = 4.11). The indicated mean values represent a price range between US$1.000 and US$5.000 US. Within the Slovenian sample of Šinko (2016) it was reported that the willingness to buy autonomous vehicles was relatively low. In this context only a quarter (25 %) of the participants was positive about purchasing fully automated vehicles whilst the remaining 75 % indicated they were not willing to buy autonomous vehicles.

2.1.3.3.2 Intention to use

The measuring of an intention to use automated cars differs from study to study. Some questions elicit whether the participants could imagine using autonomous vehicles in general or as solely used transport methods. Other questions refer to an “interest in using”. In this context 65 % of the German sample of Bock, German, and Sippl (2017) are positive about the use of fully automated cars. However more than half of the respondents refuse a future with fully automated cars as solely used transport method on roads (cf. Bock, German & Sippl (2017, p. 548). Similarly, in the survey of Gladbach and Richter (2016) more than a half (51 %) of the questioned Germans could imagine using AVs, however a third (33 %) show reserved attitudes regarding the use of AVs (cf. Gladbach & Richter, 2016, p. 9). The intention to use an AV seems slightly higher among the French sample of Payre et al. (2014). The authors report the majority of the participants (71 %) to be interested in using fully automated driving while impaired (e.g., alcohol, drug use, medication). The multinational survey of Observatorio Cetelem (2016) also investigated the intention to use of their multinational sample (cf. Figure 7, the blue columns). It was shown there that the Italian participants were most interested in using autonomous vehicles (65 %), followed by the Spanish participants (54 %), the French participants (51 %), the Belgian participants (50 %), the German participants (44 %) and the American participants (32 %) (cf. Observatorio Cetelem, 2016, p. 40).

[7] Mean value on an 11-point scale from 1 = “USD 0” to 11 = “more than USD 50,000”.

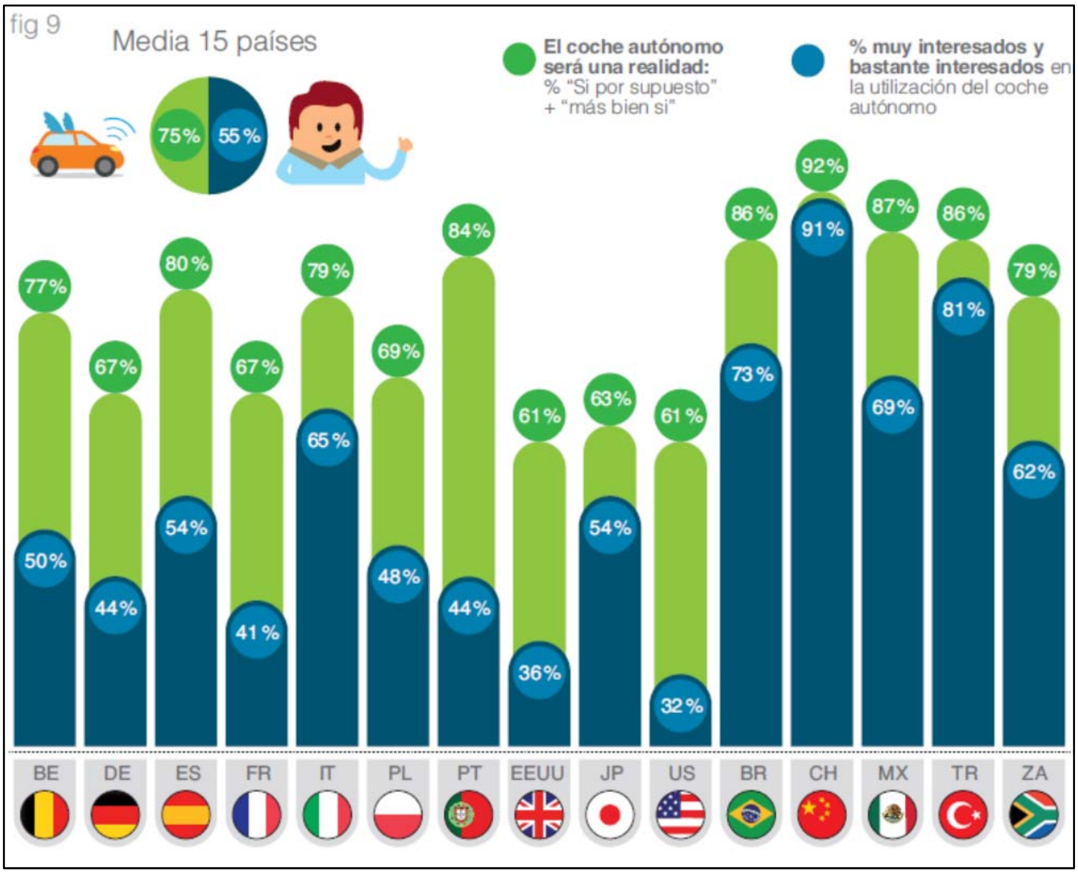

Figure 7: Intention to use 100 % autonomous cars in various countries
(Source: Observatorio Cetelem, 2016, p.40)

2.1.4 Gender differences in the acceptance of automated vehicles

The task of exploring gender issues in the context of acceptance of automated vehicles is aligned with the objective of the European Commission (EC) to integrate gender equality into policy-decision making and therefore into different policy fields.[8] In order to include the gender perspective in the development of Advanced Driver Assistance Systems (ADAS), one of the aims of WP2 of BRAVE is to deliver indicators and statistics to monitor the gender dimension during the process of implementing ADAS and developing vehicle automation. Subsequently BRAVE will pave the way for implementing gender-related findings in the further development of ADAS forming the basis for automated driving SAE level 3. By respecting the gender dimension, it is not only possible to satisfy gender equality but also to foster economic and business benefits. The anticipation of gender aspects bears the potential of saving costs (by anticipating special needs and potential obstacles to acceptance) and promoting acceptance (by taking into account the characteristics of future users). The consideration of gender issues as well as their monitoring and implementation might facilitate the introduction of vehicle automation SAE level 3 in the EU.

In order to take gender aspects into account, it is of course necessary to first investigate whether there are differences between men and women in the acceptance of automated cars and, if so, what the differences are. For this purpose, results from surveys on automated driving are presented in section 2.1.4.2. Before these findings are described, however, it is briefly discussed to what extent the technology acceptance models take gender aspects into account (section 2.1.4.1).

[8] For detailed presentation on EU policy on implementation of gender equality and the subject gender mainstreaming see the report on gender differences in the acceptance of automated vehicles by Ixmeier, Johnsen, & Funk (2017) published in WP2 of BRAVE.

2.1.4.1 Theories of Acceptance of Technology and Gender

In the section 2.1.2 above the common models of technology acceptance are presented, which are all based on “The Theory of Reasoned Action” (cf. Fishbein & Ajzen, 1975) and its further development “The Theory of Planned Behaviour” (cf. Ajzen, 1991). With regard to a measurement of technology acceptance, the “Technology Acceptance Model” (cf. Davis, 1989; Venkatesh & Davis, 2000; Venkatesh & Bala, 2008) and and the “Unified Theory of Acceptance and Use of Technology” (cf. Venkatesh et al., 2003) have been described here. Specifically for the measurement of the acceptance of driver assistance systems the “Model of Acceptance of Driver Assistance Systems” (cf. Arndt & Engeln, 2008; Arndt, 2011) and for the acceptance of autonomous driving the “Model of Acceptance of fully autonomous driving systems” (cf. Kelkel, 2015) had been developed.

To sum it up very briefly, gender is not a crucial conceptual independent basic dimension or category for describing the acceptance of technology in all these models (cf. the Figures in section 2.1.2), but an intervening or moderating variable, a background factor, alongside other categories, e.g. age, which has an influence on attitudes, subjective norms and thus, for example, on the intention to purchase or use a new technology. This also applies to the models developed specifically for the Acceptance of Driver Assistance Systems (Arndt, 2011; Arndt & Engeln, 2008) and fully autonomous driving systems (Kelkel, 2015). Briefly summarized, Arndt (2011) and Kelkel (2015) refer to “perceived product characteristics” as the main explanatory factors for the intention to purchase and use by influencing “Attitude” and “Subjective Norm” (cf. section 2.1.2.4 and 2.1.2.5). With regard to the “perceived product characteristics” differences between the sexes could now become apparent but possibly also with regard to the “subjective norm” (understood as person’s perception of whether people who are important to him / her think he should or should not perform the behaviour in question).

Regarding the results of surveys on the acceptance of automated or autonomous driving presented below, it must be said that most studies showing differences in response behaviour between men and women do not refer to a theoretical model of acceptance. The existence of potential gender gaps in those acceptance studies remains hardly explored and the category biological sex / gender was, at the very most, a sociodemographic variable among others integrated in empirical analyses without further reflection. Nevertheless, the existing literature yields some relevant findings regarding gender differences in the acceptance of automated and/or autonomous vehicles. Due to the fact that semi-autonomous vehicles (SAE level 3) were not yet available on the market at the time of the surveys, no research on direct behaviour (assuming acceptance of behavioural patterns) is provided within the present literature review.

2.1.4.2 Gender and Acceptance of automated vehicles: Findings from Surveys[9]

The findings of the studies[10], which present the answers to different aspects of the acceptance of automated driving separately for men and women, show that there are gender differences. This applies to the general assessment of this new technology, the intention to purchase, the view of the safety of automated cars and the way in which respondents would use the time during an automatic driving mode.

In the survey conducted by Schoettle and Sivak (2016) significantly more men than women said they could imagine purchasing a “completely self-driving” vehicle (11.8 % females and 19.4 % males). In the study of J.D. Power and Associates (2012) 25 % of the male participants against 14 % of the participating females stated they “definitely or probably” would purchase fully autonomous driving technology for their next vehicle on the basis of an estimated market price of $3,000. The results of the survey of Payre et al. (2014)

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[9] In addition to the studies presented in Section 2.1.3, further studies are used in this chapter, because some of the studies presented in Section 2.1.3 do not report gender differences in response behaviour at all (e.g. Bock, German & Sippl, 2017; Gladbach & Richter, 2016; Pia et al. 2016) or differences in the responses of men and women responses are presented only occasionally (e.g. Schoettle & Sivak, 2014). For a detailed presentation of the results of the surveys presented in the following cf. Ixmeier, Johnsen, & Funk (2017).

[10] The presentation of the findings is predominantly descriptive and on a bivariate analysis level. Furthermore, they refer to either fully autonomous vehicles or to some automated features only. In addition, some studies have focussed on the acceptance of different degrees of automation right up to fully autonomous vehicles and therefore considered multiple technical variations.

are similar, more men want to use automated vehicles than women, and they were more willing to purchase one. The male respondents were also more willing to use an automated car while impaired. Besides a slightly increased purchase intention the results of the survey by Casley, Jardim, and Quartulli (2013) suggest, that males are also willing to purchase self-driving technology / autonomous vehicle technology earlier after introduction than females. According to studies by J.D. Power and Associates (2012) and the AAA (2016), US-American men have a larger purchase intention for automated driving features as women. Women more often than men state their lack of knowledge about semi-autonomous technology as a reason for not wanting it within their next vehicle (in the AAA survey: 56 % females versus 44 % males) and more female participants than males stated “it would be too complicated to use” as a reason for not wanting semi-autonomous technology in their next vehicle (23 % females versus 12 % males; cf. AAA, 2016).

Within their survey among a US-sample TE Connectivity (2013) identifies safety as a primary concern of their survey participants. They report that women expect to feel less comfortable with the scenario of being driven and worry more about the safety of autonomous cars than men. Other research finding also suggest that women are more concerned about the scenario of being driven by an autonomous car and display rather fearful attitudes (cf. AAA, 2016; ACV, 2015; Casley et al., 2013; Howard & Dai, 2013). Men are less likely to express safety concerns towards autonomous vehicles than females (cf. Danise, 2015; Casley et al., 2013; Kyriakidis, Happee, & DeWinter, 2015). In the German study of the VDA (2015) especially the females express a desire to perform the driving task manually (46 % females versus 30 % males) (similar findings for California by Howard and Dai, 2013). It can be assumed from these findings that the lack of control in autonomous driving might be especially perceived by females. In the survey by Schoettle and Sivak (2014) female respondents were with one exception (data-privacy) more concerned about certain aspects of self-driving cars than the male respondents.

Men are also considering autonomous vehicle technology as more important than women, so the results of Ipsos Mori (2014), who investigated the attitudes of British citizens towards driverless technologies, and Danise (2015) concludes that “men are far more likely to express interest in self-driving cars than women” (Danise, 2015, p. 1).

But not only do men and women seem to be different from each other in regard to the intention to buy the new technology, the concerns about the new technology or the interest in the new technology, but there are also differences in how time can be used in an autonomous car. Cyganski, Fraedrich, & Lenz (2014), who investigate attitudes towards self-driving cars (and expectations on the opportunity to be productive) within a German sample report that especially “male respondents showed a slightly higher likeliness of wanting to work” (Cyganski, Fraedrich, & Lenz, 2014, p. 16). Casley et al. (2013) and KPMG (2013) report similar findings from their investigations on relatively young respondents.

The joy of driving / driving enjoyment was described as a component of the perceived product characteristics influencing attitudes toward buying DAS within the revised model of acceptance of driver assistance systems (MADAS) by Arndt (2011) (cf. Chapter 2.1.2.4). Even if Kelkel (2015) finds no significant effect of driving enjoyment on the intention to purchase driverless vehicle technology, some research indicates that especially males are concerned by the danger of losing their joy of driving in the context of the introduction of autonomous vehicles. This is suggested by the findings of ACV (2015) stating that the participating men more often cite the loss of driving enjoyment as a reason for disapproving the scenario of being driven by an autonomous car. Similar results are provided by Danise (2015), in her survey 44% of male respondents had concerns about driving pleasure, but only 23% of the female respondents.

The findings from the surveys clearly illustrate that males and females have distinct perceptions, expectations and concerns towards automated / autonomous vehicles. Males generally have more positive expectations regarding automated features / driver assistance systems in cars, the attitude of females towards automated / autonomous vehicles is rather reserved and men also seem to be slightly more willing to buy automated cars than women. In the surveys cited, women expressed more doubts about the safety of self-driving systems and a higher tendency to mistrust in such systems driving and females have other ideas than males regarding how to spend their time within self-driving vehicles.

Another factor impacting on the female purchase intention is possibly the degree to which females perceive autonomous vehicle technology / driver assistance systems as easy to use. In order to know what is seen as “easy to use” it might be helpful to consider further investigations on concrete functional requirements of women regarding automated / autonomous vehicle technology. The finding from the surveys presented in this report suggest that the most efficient way to address women's reticence towards automated/autonomous vehicles would be to address safety concerns and transfer knowledge to provide trust in the safety of these new types of cars.

2.2 The acceptance of automated vehicles in the perspective of organised stakeholders

Organised stakeholders such as for example driving instructors, insurance companies, authorities, certifiers, policy makers, bicycle federations, standardisation bodies, automobile clubs, and so forth are, either directly or indirectly, likely to be affected by AVs. It is therefore important to include their perspective so that automated vehicle technology and AVs are widely adopted in a safe and effective manner.[11]

2.2.1 Findings from the scientific literature

Neubauer and Schauer (2018) report findings from a project that regards a test region for automated and connected driving in Upper Austria. In their project a stakeholder-oriented approach was adopted and stakeholder views on automated transport logistics were revealed. Being more specific they used *world café method* in which 47 workshop participants were included (stakeholders in a decision-making role from technology providers, automotive industry, road and motorway operators, automotive suppliers, logistics providers, and public servants with responsibility of infrastructure) and interviews with 26 persons (technology providers, scenario providers, and representatives of insurance companies). In their findings the need to manage different expectations (how realistic they were) on automated transport logistics between different stakeholders is highlighted. Technology acceptance is also understood as an important factor for successful implementation and adoption of technical solutions.

A literature review by Sun, Olaru, Smith, Greaves, and Collins (2017) report a study (Begg, 2014, as cited in Sun, et al. 2017) in which transport professionals in London were hesitant towards level three and four automated vehicles before 2040. This was then contrasted with other experts in the Automated Vehicles Symposium 2014 who thought that full automation freeway driving would be feasible around 2030 (Underwood, 2014, as cited in Sun, et al. 2017). The reported differences indicate that there might be different views between different stakeholders and experts regarding the timing of widespread implementation and adoption of automated vehicles, thus when they will be common on public roads.

A holistic assessment of the impacts of automated driving in Finland was reported in a conference paper by Penttinen, Laitinen, Rämä, Innamaa, and Sintonen (2014). They had a focus on user acceptance and behaviour, traffic flow and safety, and impacts on transport system level. Their method included stakeholder interviews and workshops with representatives from industry, transport agencies, and policy makers. In their results the effects of automated driving on user acceptance and road user behaviour and interaction in traffic was highlighted. Furthermore, they discuss impacts on strategic decision making and how this would affect traffic safety and flow, as well as energy consumption and emissions. Penttinen et al. (2014) also discuss the technical feasibility or technology readiness levels, and report that some industry stakeholders plan to bring fully automated vehicles by 2020 with an optimistic prediction of 70 % fully automated vehicles by 2030. This can be compared with the predictions in Sun et al. (2017), however they also report a more cautious scenario in which it would take 30 years from the introduction to reach a 95 % penetration in traffic for automated vehicles.

[11] The scientific literature in the following literature review on stakeholder acceptance of AVs was based on searches in SCOPUS database of abstract and citation of peer-reviewed literature. The searches used Boolean operators to combine keywords related to acceptance, different stakeholders, and AVs. In total 22 searches returning 31 hits was completed. The abstracts were then examined and those that were deemed within scope was read in full-text. Finally, three full-text articles from SCOPUS were reviewed and included in the deliverable. The review of scientific literature was complemented with a review of position papers from organised stakeholders on a European level.

2.2.2 Findings from stakeholder position papers

2.2.2.1 iMobility Forum

The iMobility Forum is an organization chaired by the European Commission and co-chaired by ERTICO-ITS Europe, ASECAP and ACEA and provides a platform for ITS stakeholders in Europe. In their roadmap for automation in road transport (iMobility Forum, 2013) they lay forward their expectations on highly or full automation. The automation is expected to enhance traffic safety due to less driver workload, and by minimizing consequences of driver distraction and reduced vigilance. They also expect less congestion and less speed variation (i.e. better traffic flow) leading to positive impacts on the environment (e.g. reduced emissions and fuel consumption). In terms of implementation they predict “within the next ten to fifteen years”, but highlight legal issues that concern liability law, regulatory law, standardisation, and certification and verification as a hindrance and something that needs to be addressed. For more complex environments additional technological development is emphasised.

2.2.2.2 The European Road Transport Research Advisory Council

The European Road Transport Research Advisory Council (ERTRAC) connects road transport stakeholders to provide a common vision for transport research in Europe. They view automated driving as a key technology for future mobility and quality of life, and consequently their position is that automated driving should have a key role in European transport policy. In their automated driving roadmap (ERTRAC, 2017) AVs are viewed as an opportunity to address the societal challenges of road transports, for example safety, energy efficiency, congestion, urban accessibility, and social inclusion. Moreover, they summarize three thematic topics reflecting main challenges in the areas of society, for instance user and societal acceptance, harmonization of the regulatory approach on a European level, system and services (e.g. mobility services, artificial intelligence, digital and physical infrastructure), and vehicle (e.g. human factors, connectivity). Furthermore, their long-term vision that summarises their goals and prediction of implementation horizon is described: “in 2050, vehicles should be electrified, automated and shared” (p. 3).

2.2.2.3 The European Association of Operators of Toll Road Infrastructure

ASECAP, the European Association of Operators of Toll Road Infrastructures released a position paper on Cooperative Intelligent Transport Systems (ASECAP, 2017) in which they acknowledge potential benefits that C-ITS will bring to Europe´s transport and highlight three main areas, namely: (1) interference free coexistence with electronic road charging, (2) solid EU-wide security and data protection framework, and (3) C-ITS deployment across brands, modes and borders.

3 Road safety implications of the implementation of automated vehicles in real-life

This literature review in this chapter is on the road safety implications of the implementation of automated vehicles in real-life traffic. The literature search used the Scopus database and Google Scholar database (on the 2017-08-23).[12] The literature has been structured into a number of sub-headings that are based on relevant road safety areas and the yield of the database searches. A brief description of each sub-heading is provided under each respective area. Only scientific journals were studied in this road safety literature review.

3.1 Transfer of control/Levels of control

The transfer of control (TOC) sub-section has particular focus on the transfer of control from the vehicle to the driver. The search did, however, not generate one article that focused on the transfer of control from the driver to the vehicle which is naturally because it is an unproblematic issue with the levels of automation discussed here. Hypothetically it can be an issue when the car resumes control when the driver fails to perform sufficiently safe, i.e. the car takes the control even if the driver does not want to let go of the control.

Several aspects need to be considered interpreting the results from the literature. One important aspect is the level of automation studied. Often are automation SAE level 2 and level 3 discussed without expressing this explicitly. The authors always express the automation modes used, i.e., the problem raised is in terms of interpreting the results. If the driver is in control with the support of systems that handle horizontal (often ACC) and lateral (often lane keeping) positioning SAE level 2 automation is discussed. If the car is in control and the driver need to respond to a takeover request, i.e., the car tell the driver to tack back control in a number of seconds (often between 7 and 10 seconds), SAE level 3 is discussed.

Another important aspect is if the driver is supposed to perform a secondary task (or additional task). The Blommer et al. (2017) study looked at non-distracted drivers on SAE level 3 automation. The authors used secondary task, but, not during critical situations. Three driving scenarios were investigated: autonomous vehicle driven with full collision avoidance support, autonomous vehicle driven without collision avoidance support, and vehicle driven in manual mode. Three findings were discussed.

1. The qualitative difference in reaction behaviour between automated and manual driving (steering and braking).
2. The difference in speed variation – with higher speeds for automation conditions (with the collision avoidance system).
3. The longer reaction times for automation conditions.

Shen and Neyens (2017) studied on the other hand, the distracted driver compared to the non-distracted driver in the Blommer et al. (2017) study. ACC and LK (lane keeping) systems were used as well and the task was to react on drifts. In many respects the same results were obtained as in Blommer et al. (2017) and the drivers in the automation modes also performed less well on the secondary task.

The slower reaction times might be due to the location of the foot when driving with automated support. Young and Stanton (2007) presented results from a driving simulator experiment assessing brake reaction times of skilled and unskilled drivers under two different levels of automation (ACC and ACC that was supplemented with active steering). The authors reported a prominent increase in reaction times in their automated conditions. They suggest that this was probably due to the fact that drivers tend not to have their

[12] Only original articles and articles in press are included. The limit in years was 2010 and onwards. Please note that for quality reasons; only scientific journals were used in this literature review. The search phrases used in Scopus were: "Self driving vehicle*" or "autonomous vehicle*" or "autonomous driving*", in combination with "safety" or "safe" or "safer" or "risk" or "risks" or "accident*" or "crash*". The search phrase used in Google Scholar was: "Road safety implications of autonomous vehicles". The literature search resulted in 419 articles. The search result was narrowed down to 33 articles with a focus relevant for the State of the Art (SoA) in BRAVE. A vast number of the 419 articles that were not included in the SoA, were studies and experiments that focused on sensor and algorithm development.

foot on the accelerator pedal and are perhaps slower in moving from the floor to the brake than they are between adjacent pedals (cf. Young & Stanton, 2007, p. 55).

Larsson, Kircher and Andersson Hultgren (2014) studied a safety critical area of human control and intervention. In their experimental study, they focused on response times to hazardous situation requiring human intervention. Driver familiarity with ACC systems was also factored in. Larson et al. (2014) results suggested that the drivers with ACC-experience were quicker than the inexperienced ACC-drivers thus supporting the findings of Young and Stanton (2007). Moreover, Larson et al. also reported that both ACC-supported groups were still slower to respond than in the non-supported condition.

These results suggest that road safety improvements will be jeopardised by partial automation and may only be realised with full automation. Merat, Jamson, Lai, Daly and Carsten (2014) studied the resumption of vehicle control and conclude among other things, that as long as full automation is not widely available, system designers will need to use strategies where transfer of vehicle control goes back to the driver as it enters a more populated and complex urban environment. Strand, Nilsson, Karlsson and Nilsson's (2014) results tend to support Merat et al. (2014) in their conclusions. Strand et al. results suggested that driving performance degrades when the level of automation increases. To compensate for the degradation of driving performance, an important future research question will be the Human Machine Interface (HMI) used to convey e.g. the transfer of vehicle control.

3.2 Feedback, mental workload, SA and trust

The "Feedback" sub-section focuses on the human factors area of AV-technologies where e.g. the AV-system should be transparent and keep the driver in the information loop. Modern, complex systems are often opaque, i.e. it is not always apparent what the system is doing (and why). Keeping the driver in the loop requires, inter alia, continuous feedback from the system to the human driver. This is a necessity for control-transfer situation, i.e. AV to human driver. The area of feedback is often related to trust, or the development of trust and situational awareness, mental workload and are therefore included in this sub-section

Koo et al. (2015) studied, how the content of the verbalized message accompanying the car's autonomous action affects the driver's attitude and safety performance. Messages providing only "how" information describing actions led to poor driving performance, whereas "why" information describing reasoning for actions was preferred by drivers and led to better driving performance. Proving both "how and why" resulted in the safest driving performance but increased negative feelings in drivers. However, the authors suggest that HOW messages make drivers more passive and reduce SA. Furthermore, Endsley (2017) completed a naturalistic driving study on the autonomy features in the Tesla Model S, and recorded her own experiences, including assessments of SA and problems with the autonomy. And she argues for a greater variation of SA due to semiautonomous driving systems. The "driving" task has changed qualitatively not only quantitatively. Finally, she also showed how trust is changed over the 6 months of testing, e.g. increased trust. And Lee et al. (2015) showed how different cues promote positive evaluations and perceptions of an unmanned driving system. The cues were not verbalised as in Koo et al. (2015), the cues were human-like compared to gadget-like. The authors argue that the human-like agent evoked the feelings of social presence and this affects concepts such as perceived intelligence and safety of and trust in the agent. All participants were observers and interacted by an iPad, i.e., a number of validity aspects need to be considered and this is mentioned by the authors.

One issue of automation is that drivers can do other things while automation takes care of things (level 3 vehicles). The in or out of the loop aspect is considered next. Bashiri and Mann (2015) suggest that mental workload has been reported as one of the negative effects of driving assistant systems and in-vehicle automation. They studied driver performance and mental workload in agricultural vehicles. The results showed that reaction time and number of errors made by drivers both decreased as the automation level increased. Correlations were found between driver performance measures and subjective mental workload.

In another article by Bashiri and Mann (2014) the authors focus on mental workload and SA. Their simulator study investigated the effects of automated vehicle steering. The authors conclude that highest levels of automation reduce operators SA. It was interesting that the data on partially automation support increase SA compared to manual driving. This might be due to the double task that was studied.

The meta-analysis study by de Winter, Happee, Martens and Stanton (2014) covered 37 studies on the effects of adaptive cruise control and highly automated driving on workload and situation awareness. This review compared workload and situation awareness between manual driving, driving with adaptive cruise control (ACC), and highly automated driving (HAD). Their meta-analysis showed that ACC contributes to a small reduction of self-reported workload and a small performance improvement on self-paced in-vehicle display tasks as compared to manual driving. The results for HAD suggested that there was a large reduction of self-reported workload and a large increase on number of tasks completed on an in-vehicle display as compared to manual driving (de Winter et al. 2014, p. 208). They also show that drivers in HAD start to perform non-driving tasks “missing” the opportunity to engage in tasks to improve safety, i.e., detect objects in the environment.

3.3 Accidents and failures (systems)

Can autonomous cars reduce traffic accidents? The idea is that driver’s performance is related to accidents, i.e., human error/distraction/illness and so forth, and if humans are taken out of this equation accidents will decrease. The data points are still few and more is of course needed. There is, however, data presented that point in another direction in terms of accident involvement.

The literature with a focus on accidents is view from two aspects in this SOA. Dixit, Chand, & Nair (2016) discuss how automation is suggested to improve safety and the driving experience, but based on the data they used the authors showed that accident involvements were more frequent for automated vehicles (autonomous miles driven). Meaning that it was one accident every 48000 miles, versus 2.08 million miles (manually driven), i.e., the accidents for automated vehicles occurred more often. The authors also present data on why the automated cars disengage. The type of disengagement affected driver reaction times (system failure was the most frequent one) and disengagement was also related to trust. The level of trust was related to miles travelled as showed by Endsley (2017) as well. Furthermore, Strand et al. (2014) examined the effects of automation failures. In their experiment different system failures was induced (partial and complete). The results showed that driving performance degrades when the level of automation increases.

An important question that is raised is the extent of the exposure rate needed for accident data-based comparisons. This question was raised by Kalra and Paddock (2016). The authors argue that it will take too long time for society to get a reliable and valid answer and therefore argue for another approach. Hence, the authors describe how many driven miles that is needed in order to be sure concerning or gain faith in AV safety. However, Kalra and Paddock’s calculations are based on a fleet of 100 AV: s and the authors do not discuss the number of cars that will be driven or motivate why 100 cars is chosen. It is of substantial value that the figures are calculated. However, the question remains if it is even possible to evaluate the safeness of AV with only 100 AV: s on the streets (with different levels of automation).

3.4 Driver and infrastructure condition

This sub section deals with driver and infrastructure conditions and their relatively importance for road safety. How is driver state and the state of the infrastructure related to road safety when level of automation is considered. All in the light of automated cars. First. One of these issues was addressed by Gold et al. (2016) when they studied the importance of traffic density. In their experiment the authors also included distracted versus non-distracted conditions. As predicted, road density (number of cars surrounding the studied car) affected driver performance both qualitatively and quantitatively (increased density reduced driver performance measured by time-to-collision (TTC)). The driver state manipulation did not affect in such a way as density. One interesting (and replicated effect) was that participants put their hand on the steering wheel with a similar reaction time. But the analysis of the situation was more difficult when density was high. The authors discuss the validity of the task and argue for its relevance. The task was to avoid an obstacle in the driving lane.

Driver state are also studied further. Takeda et al. (2016) argue that it is important to understand the state of drivers’ attention as they ride in Level 3 self-driving vehicles, because they might be required to take manual control of the vehicle in certain situations. As mentioned earlier, driving SAE level 3 vehicles compared to level 2 vehicles comes with a vehicle that informs the driver that it s/he is to take back the control of the vehicle compared to a vehicle that supports driving with a driver in control at all times. Takeda et al. (2016) compared electrophysiological signals from drivers and passengers and found several differences. All in all, the differences suggest that visual information processing load was lower for passengers compared to drivers. However, the effect of context was also significant. i.e., effects of sections were obtained. Passengers "behave" differently especially in the urban sections. Another article (Biondi, et al., 2017) considered heart rate instead. And the authors studied participants from three different age groups (21-34, 35-53, 54-70 years old). The combined effects of mental workload (induced by interacting with the in-vehicle infotainment system via voice) and aging were studied. The results revealed that average heart rate increased as the secondary task became more demanding. Furthermore, a significant task by age interaction suggested that as the secondary task became more demanding, younger drivers showed an increased heart rate compared to older drivers. Another article that could be placed in the methodology section in this SOA as well as is presented here since the method is used to classify distraction (Tango and Botta, 2013). The authors argue that driver state detection is very important for avoiding negative effects of driver support systems. They introduce a vehicle dynamics data to be able to detect distraction. By the use of different machine learning (ML) methods the authors argue for the support vector machine (SVM) method as the best distraction classifier.

3.5 Additional effects and modelling

A number of articles that was given by the search completed concerns modelling or driver models or related aspects to modelling. In this sub-section these articles were included.

There are many theories within the field of psychology, human factors and HMI. Particularly useful within the BRAVE context is the theoretical work done by Horrey, Lesch, Mitsopoulos-Rubens and Lee (2015). Horrey et al. (2015) presented a model on driver skill and judgement calibration that is based on the lens model (Brunswik, 1955) for information selection and utilisation. Using this model Horrey et al. describe the implications for calibration and errors in calibration. The purpose is to improve our understanding of driver distraction, in-vehicle automation and autonomous vehicles. Horrey et al. (2015) model provides a useful framework where an understanding of calibration could provide important insight into driver decision-making and behaviour in regard to vehicles of semi-autonomous nature or drivers of non-autonomous nature who encounter AVs. The both driver groups' performance and safety may be influenced. Another model is presented by Zhang et al. (2016). They suggest that traffic accidents are likely to occur at inter-sections and that each driver behave differently. It is argued by the authors that this model can be used to determine the individual characteristics of the driver. The authors have as a result of this study created a model that predicts intersection behaviour.

In the area of models and frameworks Gadepally et al. (2014) present a framework for the estimation of driver behaviour at intersections, with applications to autonomous driving and vehicle safety. The framework uses driver behaviour and vehicle dynamics as a hybrid-state system (HSS). Comparison is made between the proposed framework, simple classifiers, and naturalistic driver estimation with good results for the HSS.

Another article, only indirectly focusing on automation is the collision based method developed by Åsljung et- al. (2016). This paper compares a collision-based measure against one that relates to an inevitable collision state. The result showed that using inevitable collision states was more efficient. This is mainly an article that provides a measure to calculate if automated vehicles increase or decreases in accidents involvement by using another method. In the same line of reasoning is the article written by Siebert et al. (2014). The authors studied the effect of time headway (THW) and speed on subjective ratings on risk, effort, control etc. Time headway was varied eightfold (0.5-4 s in 0.5 s increments) and speed was varied threefold (50, 100, 150 km/h). The main finding is that a 2-second threshold was found, i.e., with different results that were related to THWs over or below 2 seconds. Meaning that a THW above 2 seconds did not affect subjective ratings in a systematic way. When THW were 2 seconds or below another picture emerged.

3.6 Influence on non-AV drivers

In this sub-section the focus is on the influence of AV on non-AV drivers. This area of AV is also one of the main purposes of the BRAVE project.

Gouy, Wiedemann, Stevens, Brunett and Reed (2014) studied advanced driver assistance systems (ADAS) that are entering the driver task in semi- and fully automated vehicles with mixed traffic situations in focus. The study focused on vehicles equipped with automated systems that took over lateral and longitudinal control of the vehicle and the interaction with unequipped vehicles that are not fitted with such automated systems. Gouy et al. (2014) performed a simulator study with 30 participants. The participants were asked to follow a lead vehicle that passed platooning vehicles (on a three-lane motorway) with either a short (0.3 s) or long (1.4 s) time-headway (THW). Gouy et al. (2014) results suggest that participants adapted their driving behaviour by displaying a significant shorter average and minimum THW while driving next to a platoon holding short THWs as when THW was large. They also spent more time keeping a THW below a safety threshold of 1 s. Their results also suggest that there were no carryover effects from one platoon condition to the other, indicating that the effect was not lasting. The effect is interpreted as a temporary behavioural adaptation to the presence of autonomous vehicle functionality, i.e. platooning.

3.7 Methodology / technical development

The focus of this methodology/technical development sub-section is to highlight the influence of AV on safety related research. However, the development of AV related safety is and has been immersed in the complexities of its own technological adolescence. Insight into the background of this area is important if one is to understand future human machine interface challenges.

Minderhoud and Bovy (2001) developed method for calculating possible safety indicators for assessing AV functions. Examples could include Autonomous Intelligent Cruise Control (AICC). Minderhoud and Bovy's study describes two safety indicators based on the time-to-collision (TTC). The indicators calculate vehicle trajectories collected over a specific time horizon for a certain roadway segment instead of the traditional TTC calculation. Calculating an overtaking manoeuvre is a challenging task in the development of any AV. Some of the reasons for overtaking manoeuvres being challenging is because of the hazardous nature of the manoeuvre and the dynamic nature of other drivers. Naranjo and González (2008) used methods based on a mathematical set of (fuzzy) rules for calculating an AV overtaking manoeuvre. Lu, Wevers and Van Der Heijden (2005) discuss AV technology that has road traffic safety potential. Key issues are identified pertaining sensor fusion, to improve robustness, reliability and operation permanence. Moreover Lu et al. raise the importance of distinguishing collision avoidance between two (or more) vehicles, and between a vehicle and (one or more) vulnerable road users.

Schieben, Griesche, Hesse, Fricke and Baumann (2014) studied three different interaction designs of automatic steering intervention. Schieben et al. had forty participants in their study with three experimental groups that had automatic steering intervention: (i) Pure automatic intervention, (ii) directed haptic warning plus automatic intervention, (iii) and undirected acoustic warning plus automatic intervention. There was also a baseline group. The background of this experimental study by Schieben et al. was an observation by the authors that drivers tend to only brake in rear-end collision situations and did not use an evasion manoeuvre i.e. steering around an object to avoid an incident. Schieben et al. (2014) results suggest that the automated steering intervention reduced the number of total crashes by 30–50 %. A complete reduction of crash was not achieved by the automated system because of driver interference (ibid.). Lee, Abdel-Aty, Choi and Huang (2015) used a Bayesian Poisson lognormal simultaneous equation spatial error model (BPLSESEM) for identifying potential pedestrian accident hotspots/blackspots (in Florida, USA). The authors report some success in identifying blackspots which could be of some interest in AV-developer where an AV could have pre-emptive pedestrian safety strategies in known hotspots/blackspots areas.

Fernandes and Nunes (2012) simulated and refined the communication delays that occur with platooning AVs. In the simulation tests, all of the eight vehicles reached a point where they were only 60 cm apart from each other. The simulation results suggest that the proposed information-updating algorithms were appropriate for safely dealing with platooning vehicles. The locus of the sub-optimal performance in Schieben et al. (2014) suggests that if human machine interface issues (HMI) are not properly addressed by system developer, it is likely that the effect of AV on road safety will not be fully realised.

Li, Li, Cheng and Green (2017) present a new way to identify driving style in terms of transition patterns between them to see how they are interrelated. Driving behaviour in highway traffic was categorized into 12 manoeuvre states by Li et al. (2017). A conditional likelihood maximization method was used to extract typical manoeuvre transition patterns that could represent driving style strategies. A random forest algorithm was adopted to classify the driving styles. Li et al. (2017) results suggest that there were five manoeuvre states that could be used to classify driving style reliably; free driving, approaching, near following, constrained left and right lane changes. Li et al. (2017) also present a driving model on operational, tactical and strategic levels and that classify the manoeuvres. The methods used in Li et al. can e.g. be used to personalise the *behaviour* (or settings) of the AV-functions depending on contextual factors and personal preference, thus aiding acceptance.

Bärgman, Smith and Werneke (2015) explored drivers' comfort- and dread-zone boundaries in left turn scenarios. The authors define the comfort zone as “an implicit spatiotemporal envelope that extends in front of the driver-vehicle-system, within which the drivers feel comfortable in every day normal driving” (Bärgman et al., 2015, p. 171). They define the dread zone as a zone “with a smaller safety margin that drivers will not voluntarily enter, but can push themselves into when conditions provide additional motivation” (Bärgman et al., 2015, p. 170). The overall purpose with their approach was to understand driver acceptance of ADAS to support development of sufficient automated driver assistance systems. The results revealed that drivers in a hurry accepted shorter time gaps and conclude that drivers use two contextually dependent safety zones, i.e., the comfort and the dread zone, based on driver condition.

4 Ethical implications of the introduction of automated vehicles

One of the aims of BRAVE is to study the requirements and expectations of the users of automated vehicles. To know what (potential) users and the society are thinking about issues related to automated cars is important for the deployment of this new technology. The project description of BRAVE states: "While developing and implementing automated vehicles, it is necessary to ensure that the societal consensus regarding the acceptance of automated vehicles is met, and the social, legal, economical and ethical implications are considered sufficiently while designing new technical features". Therefore, dealing with ethical issues of autonomous driving is important for two reasons:

- On the one hand ethical considerations related to automated vehicles might have an important impact on the way those vehicles are seen by the public. This places a considerable responsibility on the programmers and designers of automated vehicles to design ethically and socially acceptable vehicles (cf. Gerdes & Thornton, 2015; Bonnefon, Shariff & Rahwan, 2015; Borenstein, Herkert & Miller, 2017; Sütfeld, Gast, König & Pipa, 2017).
- On the other hand, ethical considerations are to be incorporated into the technical development of autonomous cars.

The importance of ethical issues for the development and deployment of automated vehicles is demonstrated not least by the fact that an ethics commission on "automated and networked driving" was set up in Germany by the Federal Government, which presented its findings and recommendations in June 2017 (cf. Ethik-Kommission, 2017; Ethic Commission, 2017). A discussion on the ethical aspects of automated cars has only been going on since 2013 / 2014. This is hardly surprising, as the development and dissemination of autonomous vehicles have been considered unlikely in the near future for a long time. In the last three years an increasing amount of literature on the extent to which ethical issues need to be taken into account in the development of autonomous cars can be found. However, the discussion on the ethical aspects of autonomous vehicles does not start from scratch. There are already considerations about the relationship between humans and autonomous robots in the field of "machine ethics" or "robot ethics" (cf. Lin, Abney & Bekey, 2012; Goodall, 2014b; Millar, 2014; Dennis, Fisher, Slavkovik & Webster, 2015; Kumfer & Burgess, 2015; Alaieri & Vellini, 2016; Borenstein, Herkert & Miller, 2017; Etzioni & Etzioni, 2017).[13] Some of these considerations can now also be found in the discussion on ethical issues of automated cars.

But how are ethics and morality related to the subject automated / autonomous cars? In every society there are certain values, norms and rules about how human coexistence should be structured, what is allowed and legitimate and what is not. This could be called the morality of a society. Ethics as a philosophical sub-discipline examines, among other things, the moral concepts of a society. In addition, normative ethics aims to formulate general principles and criteria for assessing correct moral action (cf. Köberer, 2014). Even if it doesn't look like this at first glance, road users often make ethical decisions, the decisions of a car driver often comprise ethical components, even if the car is not in immediate danger or involved in a crash (cf. Goodall, 2016; Sütfeld, Gast, König & Pipa, 2017, p. 2).However, ethicists are not only concerned with human morality, but also with that of machines and robots. Non-human agents become interesting for ethicists when they can act independently without being led by humans in a certain situation, in other words: if they can act autonomously. Autonomous cars can be understood as a special type of autonomous operating robot: "As agents moving through an environment that includes a range of other road users (…) automated vehicles continuously interact with the humans around. (…) An obvious question then arises: can automated vehicles be designed a priori to embody not only the laws but also the ethical principles of the society in which they operate?" (Gerdes & Thornton, 2015, p. 88).[14]

[13] The question on the extent to which autonomous robots can or should be regarded as independent moral agents, who can or should be held morally responsible for their actions, is not discussed in more detail here (cf. Hevelke & Nida-Rümelin, 2014; Millar 2014, 2016; Gerdes & Thornton, 2015; Dennis, Fisher, Slavkovik & Webster, 2015; Vellino & Alaeri, 2016; Etzioni & Etzioni, 2017; Nyholm, 2017).

[14] The question of how autonomous cars should behave to animals is not discussed in this report, regarding questions of animal ethics see Bendel (2014, 2016).

The ethical design of automated cars must of course be based on the fundamental ethical principles of a society. Individual self-determination / autonomy and physical and psychological integrity (safety) are two fundamental ethical principles of modern societies (cf. Ehtik-Kommission, 2017; Millar, 2016). If self-determination and protection are fundamental ethical principles, then it becomes clear to what extent ethical questions arise in the case of automated vehicles: How can automated cars impair or promote self-determination / autonomy and protection / safety of the road users?

Therefore, the following literature review[15] will discuss to what extent the ethics of automated or autonomous cars affect the fundamental ethical principles mentioned above. Looking at the scientific literature and the public discussion on the ethical implications of autonomous cars, it becomes apparent that the following questions are addressed in particular:

- If the driverless vehicle technology without any supervision of humans is safer than human drivers, should non-automated driving be prohibited?
- How should a self-driving car be programmed and behave in case of an unavoidable crash?
- Who should decide about the ethical principles that automated cars should follow? What are Citizens thinking about the ethical programming of autonomous cars?
- Who is responsible for the behaviour of autonomous cars, who is morally and legally responsible (e.g. in the case of a crash)?
- How can privacy /data protection / the right to informational self-determination be guaranteed?

Most of the contributions to the discussion on ethical implications deal – in the broadest sense – with the question of ”autonomous cars and crash or safety”.[16] For this reason, this topic will occupy most of the attention in the following literature review. Most authors assume that these ethical questions neither have been sufficiently and transparently discussed, nor has the car industry yet accepted the need to discuss the ethical issues of autonomous cars. But the way autonomous vehicles are programmed and will behave in the ‘social interaction’ of road traffic will determine their societal acceptance (cf. Lin, 2015).

The topics of responsibility and privacy are discussed in detail in the chapter on legal issues of autonomous cars (cf. sections 5.1 and 5.2), although there is a great overlap between ethical and legal issues – of course, the other ethical questions are also linked to legal issues. Aspects that raise ethical issues in a very broad sense, such as autonomous cars and environmental protection, are not dealt with in this chapter.

One last important comment in advance: Ethical issues related to crashes outlined and discussed below are still hypothetical, since the authors always base their considerations on highly or fully automated cars (i.e. SAE-Level 4 and / or 5), but highly and full-automated cars are not yet available on the market.

[15] The following databases were used for the literature review on ethical implications: TRID, Scopus, OLC Philosophy, PsycINFO, PSYNDEX, Elsevier / ScienceDirect, DOMA and TEMA. Search words were “automated car”, “self-driving car”, and “autonomous car” / “vehicle”, in combination with “ethics” or “moral”. In the 35 articles (some of which were not peer-reviewed) dealing with ethical implications in greater detail, the lists of references were used to find more literature. Thus 15 further relevant articles were found. In addition, the Internet was searched for articles on technology pages and reports from private and public institutions.

[16] In a certain sense, this is no wonder, since wonderful headlines can be formulated here, like: “Why Self-Driving Cars Must Be Programmed to Kill” (www.technologyreview.com/s/542626/why-self-driving-cars-must-be-programmed-to-kill), “Self-Driving Cars Will Kill People. Who Decides Who Dies?”(www.wired.com/story/self-driving-cars-will-kill-people-who-decides-who-dies), “The Robot Car of Tomorrow May Just Be Programmed to Hit You” (www.wired.com/2014/05/the-robot-car-of-tomorrow-might-just-be-programmed-to-hit-you) or “An ethical dilemma: When robot cars must kill, who should pick the victim?” (http://robohub.org/an-ethical-dilemma-when-robot-cars-must-kill-who-should-pick-the-victim) [All accessed at 02.11.2017].

4.1 If the driverless vehicle technology without any supervision of humans proves to be safer than human drivers, should non-automated driving be prohibited?

The widespread introduction of fully automated vehicles entails the hope that the number of crashes and the associated injuries, fatalities and accident costs will be significantly reduced. A strong moral and ethical argument in favour of the development and introduction of Advanced Driver Assistance Systems (ADAS) and fully autonomous cars is the possibility of significantly reducing the number of crashes and thus the number of injuries and fatalities (cf. Hevelke & Rümelin, 2015b; Sparrow & Howard, 2017). According to the German Federal Statistical Office, 67 % of accidents involving personal injury are caused by driver misconduct (cf. Sütfeld, Gast, König & Pipa, 2017), other studies on crashes and road safety conclude that at least 75 % of crashes (cf. Parliament of New South Wales, 2016), if not more than 90 % of crashes (cf. Fleetwood, 2017; NHTSA, 2008) are caused by human error (e.g. due to inattention, excessive speed, driving under the influence of alcohol or drugs, violation of traffic rules etc.).

It is assumed, that the more driver assistance systems (DAS) – up to the point of complete control by the car – will be used, the more the number of crashes and associated deaths, injuries and costs will decrease.[17] Well-programmed automatic driving systems would probably be superior to humans in many crash scenarios, e.g. a crash with a pedestrian: To decide what to do in the case of a collision many variables need to be taken into consideration: Is there enough time to stop? Is it dangerous to brake the car hard? Is it better to hit the pedestrian or to swerve? If the car should get out of the way, should it swerve to the left or to the right, is it possible to drive into the opposite lane? “While all this happens within seconds – not enough time for careful deliberations by human drivers – an autonomous car could have the virtue of a (presumably) thoughtful decision-making script to very quickly react in an optimal way” (Lin, 2015, p. 74).

Due to the predicted massive decrease in the number of crashes, there has recently been a discussion as to whether it seems ethically necessary to prohibit non-autonomous driving in the future, provided that cars driving autonomously are safer than cars driven by humans. Thereby two aspects have to be distinguished.

- If the driverless vehicle technology without any supervision of humans is safer and poses a lower risk to third parties than human drivers, it seems morally or ethically necessary to prohibit people from driving or controlling an autonomous car.
- As soon as autonomous cars are safer than cars driven by humans, it seems morally or ethically necessary to prohibit selling and using non-autonomous vehicles.

Sparrow and Howard (2017) argue that human driving should be prohibited in the future: “As long as driverless vehicles aren’t safer than human drivers, it will be unethical to sell them. Once they are safer than human drivers when it comes to risks to 3rd parties, then it should be illegal to drive them: at that point human drivers will be the moral equivalent of drunk robots” (Sparrow & Howard, 2017, p. 206). These authors are not alone with this opinion (cf. Stockburger, 2017; Mancuso, 2016).

Therefore a conflict between the two ethical principles of self-determination and protection arises. Prohibiting the driving of manually controlled cars would limit the individual's freedom of choice, but at the same time would increase safety for society as a whole. In the near future the society / the government will have to make a decision on how to weigh self-determination and protection against each other. The German “Ethics Commission on Automated and Networked Driving”[18] has adopted the following ethical rule on this

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[17] However, the thesis that the number of crashes will fall significantly is not entirely uncontroversial (cf. Goodall, 2014a; Bengler, Winner & Wachenfeld, 2017). „However, a closer analysis of these statistical evidence for humans as the primary cause of crashes shows that they are based on incomplete and thus misleading data, because only crashes that have occurred are taken into account: there is a lack of data on cases where no crashes have occurred, because people have actively intervened to absorb system errors (technology, environment, other people). This means that it is impossible to determine from the crash figures whether the replacement of the human driver actually increases the overall safety of the system“ (Zimmer, 2017, p. 459 [own translation]).

[18] The Ethics Commission was composed of scientists, judges, representatives of the churches, representatives of the automobile industry and consumer protection associations (cf. Ethik-Kommission, 2017). It was the first (and so far the only) Commission to deal explicitly with ethical issues of autonomous driving.

subject: “The introduction of more highly automated driving systems, especially with the option of automated collision prevention, may be socially and ethically mandated if it can unlock existing potential for damage limitation. Conversely, a statutorily imposed obligation to use fully automated transport systems or the causation of practical inescapabilty is ethically questionable (…) (prohibition on degrading the subject to a mere network element)” (Ethics Commission, 2017, p. 7).

4.2 Autonomous vehicles and crashes: How should a self-driving car be programmed and behave in case of an unavoidable crash? The view of the ethicists.

For some years now, philosophers and ethicists have been working on the question of how autonomous cars should behave in the event of a crash. This question is considered important because all ethicists assume that crashes will continue to occur in the future. Even if only autonomous vehicles (level 4 or level 5) were still on the road, crashes cannot be avoided in the future (cf. Bonnefon, Shariff & Rahwan, 2014; Goodall 2014a, 2014b; Hevelke & Rümelin, 2014; Frison, Wintersberger & Riener, 2016; Gogoll & Müller, 2016; Coca-Vila, 2017). Even in the unlikely event of no technical failure of the systems or sensors of the car, crashes will occur, because of unpredictable other road users like animals, pedestrians or cyclists. In principle, any programming of how a car should behave (not only) in crash situations is an ethically or morally based decision. This means that autonomous cars or rather the programmers of the algorithms will have to make ethical decisions in the future (cf. Millar, 2017).

Ethicists also point out that it can’t be the solution to hand over control to the vehicle occupants in a crash situation where an ethical decision has to be made, because it would take too long for people to get an overview of the situation and take control (cf. Lin, 2015; Lu et al. 2016; Nyholm & Smids, 2016; Zimmer 2017). The more automated control systems are in the car, the less likely it is that the occupant of a car can take control in time, because he/she is not paying attention to what happens on the street. The German Ethics Commission on "Automated and networked driving" even demands that an abrupt transfer of control from the self-driving car to the occupant (and thus ”driver”) should almost never take place (Ethics Commission, 2017, p. 9).

The ethicists are now discussing the problem of crash behaviour using very specific thought experiments. The way of argumentation is relatively similar for all authors: It is based on a car that runs autonomously without human intervention or human control / monitoring (i.e. SAE levels 4 and 5). The autonomous vehicle is involved in an unavoidable crash. In the course of the crash it cannot be avoided to injure or even kill a person but it is possible to choose who will be harmed by the crash. This ethical thought experiment on a moral dilemma is called the “trolley problem” and was first introduced by Philippa Foot (cf. Goodall, 2016; Gogoll & Müller, 2016; Contissa, Lagioia & Sartor, 2017).

This is what the original thought experiment “trolley problem” is about: A train has got out of control and five people who are standing on the track would be run over and killed by it. Now someone is standing at a switch. By changing the switch, the train can be diverted to another track. Unfortunately, there's one person on this track, too. Is the death of one person (by actuating the switch) acceptable in order to save the lives of five people?[19] The “trolley problem” describes a moral dilemma, a hard case, because there is no clear ethically or morally right answer to the question of whether the switch should be changed or not. Either way, harm to persons is unavoidable and there are good ethical reasons for one or the other behaviour. Ethicists conclude from the thought experiment that autonomous cars will need to engage in crash-optimization, where crash-optimization means to reduce the amount of harm “and this could mean a forced choice between two evils (…) Crash-Optimization Means Targeting” (Lin, 2015, p. 72). To discuss ethical issues on automated cars the “trolley problem” is transformed into the “tunnel problem” (Millar, 2014) or “bridge scenario” (Goodall, 2014b). Both crash descriptions and other crash scenarios discussed in the literature are basically similar. An autonomous car is driving along the street, when another road user (for example a

[19] An alteration of the “trolley problem” is the “footbridge dilemma”: To push someone off a bridge would derail or stop a train and save the five people on the track. There are empirical studies that show that most of the participants say that they would operate the switch (in the original trolley scenario), but only a minority says they would push someone to the train to save the humans on the track (cf. Sütfeld, Gast, König & Pipa, 2017).

pedestrian or a cyclist) appears in the lane. There's no way to slow down in time so that someone gets killed, that can also be the passenger depending on which decision is made.

Even if these situations, in which there are only choices that allow the protection of one road user by the death of another road user, are very rare, “their emotional saliency is likely to give them broad public exposure and disproportional weight in individual and public decisions about AVs” (Bonnefon, Shariff & Rahwan, 2015, p. 3). The programming of algorithms that have to ”process” crash situations like the “tunnel problem” or the “bridge scenario” requires decisions that obviously address ethical issues: on the basis of which criteria do the algorithms make the decision how the car should behave and who is injured or who could be fatally injured by the crash? The ethics researchers state that it is not better from an ethical point of view if in such a crash situation it is either not at all or randomly or arbitrarily ”decided” who is to be harmed (cf. Nyholm & Smids, 2016). Due to the capacity of their computer hardware, autonomous cars could analyse the accident events in fractions of a second, calculate the consequences of the accident and have enough time to choose between the alternatives because of their reaction speed. For autonomous cars an algorithm can be developed calmly long before a possible accident occurs (cf. Goodall, 2016). For some situations where a person is not able to react fast enough, it might even be useful if a decision is made on the basis of an algorithm, provided that a lot of variables / sensor data can be evaluated in a very short time, and that the consequences of the accident can be reduced (compared to a human decision making). Unlike autonomous cars, human drivers would not be reproached ethically in a “trolley problem” kind of crash if they behaved incorrectly, since it is assumed that they are surprised and objectively unable to see the consequences of their behaviour due to the short time frame of a split-second crash situation (cf. Gogoll & Müller, 2016, p. 686; cf. Hevelke & Nida-Rümelin, 2014; Fournier, 2016; Trappl, 2016; Zhang, 2017). „Human drivers may often make poor decisions during and before crashes. They must overcome severe time constraints, limited experience with their vehicles at the limits of handling, and a narrow cone of vision“ (Goodall, 2014b, p. 60.

Recently, a number of scientific articles have been published discussing which ethical approaches and principles are best suited to the design of algorithms for ethical decision making in autonomic cars and how these ethical principles can be mathematically formalized (cf. Goodall, 2014a, 2014b; Hevelke & Nida-Rümelin, 2014, 2015a, 2015b; Gerdes & Thornton, 2015; Bonnefon, Shariff & Rahwan, 2015; Kumfer & Burgess, 2015; Bringsjord & Sen, 2016; Bench-Capon & Trevor, 2016; Fournier, 2016; Thornton, Pan, Erlien & Gerdes, 2017; Leben, 2017; Contissa, Lagioia & Sartor, 2017; Coca-Villa, 2017; Kinjo & Ebina, 2017).[20] The aim is to find an ethical approach from which one can deduce ethically unproblematic, concrete rules of accident behaviour. Two approaches in particular are discussed in the literature: utilitarianism / consequentialism and deontological ethics.

- According to a utilitarian moral doctrine, an algorithm has to be programmed to minimize the number of people who get harmed. The basic idea of the utilitarian approach is that an action or behaviour is morally correct if the greatest benefit for the greatest number of people could be achieved. When applied to a possible crash of an autonomous car, this means that a utilitarian algorithm would be programmed in such a way that the costs of an accident would be as low as possible. This could mean that in a crash situation the control algorithm decides that the occupant of the car is sacrificed (because only one human life is at stake instead of, for example, two or more pedestrians). On the one hand such an algorithm would look at which reaction of the car would affect the smallest number of people. On the other hand, it would also be considered which reaction would generate the lowest costs (measured in money).
- In a deontological approach, humans must never be treated only as a mean to an end because of human dignity. An ethically right action is one in which another human is not violated. The “difference between doing an action simply because it is right and not because of the consequences” differentiates deontological ethics from utilitarianism (Kumfer & Burgess, 2015, p. 132). In a deontological approach

[20] Some authors not only discuss which approach is best suited, but also how these ethical principles can be mathematically formalized. As the question of how to convert or transform ethical rules into algorithms is a very specific question within science, the report does not go into more detail on this issue. However, it seems that there are still many problems to be solved. There is no obvious way to encode complex human morals effectively in software. “Computational moral modelling is in its infancy. (…) The fields of moral modeling and machine ethics have made some progress, but much work remains” (Goodall, 2014a, pp. 100).

an automated car must follow certain rules which respect the value of humans. Asimov's Three Laws of Robotics are an example for a deontological approach (cf. Goodall 2014b; Gerdes & Thornton, 2015).

The discussion in the literature makes it clear that every ethical approach has its flaws. Critics of utilitarianism insist that if an infringement on another person for one's own ends is wrong between individuals, it is just as wrong between society and individuals. At first glance, a utilitarian approach seems unproblematic. But the problem is to what extent a single human being's rights can be restricted for the greatest possible benefit of all. From a deontological point of view, only under very strict conditions and within narrow limits. A crash algorithm that is utilitarian oriented violates the principle of human dignity, according to which individual lives cannot be summed up against each other (cf. Lin, 2015; Ethics Commission, 2017). “A violation of some person's fundamental rights cannot be legitimized on the basis of benefits for others, no matter how large” (Hevelke & Nida-Rümelin, 2015b, p. 622). Deontological ethics can provide guidance in many situations, but the problem is that it is rather unsuitable for programming crash algorithms since no rule can ever cover all aspects of road traffic and it's difficult to ”transform” complex human ethics in a set of rules (cf. Goodall, 2014b). Any rule has its problematic aspects, as the following three examples discussed in the literature show.[21]

First of all, one might ask oneself whether it is relevant who caused the accident to decide who will be ”harmed” (this would follow a deontological ethical setting). In this context, the question of responsibility is inextricably linked to the question of justice / fairness. For example: A pedestrian causes the crash, the autonomous car has to decide to run over the pedestrian, to sacrifice the car occupant or to harm another road user. It could be ethically justifiable to say that the one who caused the crash must, so to speak, also bear the consequences. But this is only eligible under very strict and tight framework conditions which are not given in reality. The first problem in many crash situations is that it is nearly impossible that the sensors of an automated car can detect who caused the accident (e.g. the child that steps into the lane may have been pushed into the street by another child, but the sensors can't detect the second child), so that the car cannot make a moral statement of guilt. Secondly, an algorithm which is based on the responsibility becomes (ethically) problematic if the possible injuries caused by the crash will differ considerably between those involved in the crash. Take the example again: A pedestrian causes the crash and it might be possible to prevent the collision with an emergency brake by the car. The potential risk of injury from this emergency braking for the car's occupants is undoubtedly considerably lower than the expected injuries to the pedestrian if the vehicle does not come to a halt in time. Last not least it does not seem desirable to have a machine that makes ethical findings about guilt or responsibility and, based on these findings, makes decisions about life and death (cf. Hevelke & Nida-Rümelin, 2015a).

Another way of programming a “crash-optimization”-algorithm could be to stipulate that, in the event of an unavoidable crash, the road user that is best protected should be chosen as the target (this would follow an utilitarian approach). This seems at first glance plausible and ethically correct because it is highly likely that the better protected road user will suffer less damage than less protected road users. If one carries out the thought experiment with other road users, crash situations become apparent very quickly, in which the rule will be problematic (cf. Hevelke & Nida-Rümelin, 2014). In the event that the other parties involved in the crash are motorcyclists, one of them is wearing a helmet and the other one is not, then the autonomous car would have to choose the motorcyclist with the helmet as its target, since her / his brain damage is expected to be significantly lower than that of the motorcyclist without a helmet (cf. Goodall, 2014a). Apart from the not unimportant question of whether it is ethically justified that, paradoxically, the one who protects himself must suffer from this protection, unintended changes in behaviour could occur. In consequence there could be false incentives such as buying ”unsafe” vehicles or behaving unsafe, e.g. not wearing a helmet on the bicycle or the motorbike, as this reduces the likelihood of being involved in an accident by an autonomous car (cf. Gerdes & Thornton, 2015). And by the way, an algorithm that follows the approach of reducing costs in the event of an accident means that it is always better for pedestrians to move in a group than alone.

A further, very easy rule for programming the autonomous car could be the default: “The protection of car occupants is paramount!” This rule contradicts both a utilitarian and a deontological approach and also causes ethical problems. In the case of an unavoidable crash and collision, the autonomous car would have to

[21] It is currently under discussion whether it is not possible to develop correct algorithms by combining different ethical approaches and incorporating results from AI research (c.f. Goodall, 2014b; Thornton, Pan, Erlie & Gerdes, 2017; Lugano, 2017).

select the obstacle, which causes the least damage to the car and its occupants. This could be a pedestrian instead another car (cf. Lin, 2015) and among pedestrians the smaller and lighter (children); walls, masts, houses etc. should be avoided. It is obvious that such a crash algorithm is morally problematic (cf. Contissa, Lagioia & Sartor, 2017; Coca-Vila, 2017).

The discussion of possible ethical approaches and rules shows, that there are crash-scenarios which are hard cases. Any criteria for "crash-optimization" in a “bridge” or “tunnel problem” are ethically questionable or untenable. When programming algorithms, it must also be noted that no human being may be discriminated and disadvantaged on the basis of whichever characteristic, i.e. neither sex, race, age, ethnic origin etc. Not to mention that such a pre-established selection is legally prohibited (cf. Lin, 2015; Ethik-Kommission, 2017). An algorithm that in case of doubt selects very old people instead of small children would be ethically wrong, since obviously members of a certain group are discriminated.

The ethicists’ deliberations have now, of course, been taken into account by technology-interested journalists and also by representatives of the automobile industry. But not all of them agree with the ethicists' considerations based on the "trolley problem" and the conclusions drawn from it, for two reasons (cf. Gowling WLG & UKAutodrive, 2016; Johansson & Nilsson, 2016; Rose, 2015; Hucko, 2016; Asendorpf, 2017). First of all, a crash scenario that is similar to the scenario described in the “trolley problem” is very rare and thus irrelevant – compared to the safety benefits gained by using automated cars. Secondly, the problem is regarded as solvable: „We argue that the self-driving vehicle shall have the responsibility not to get surprised in a way that the trolley problem can show up” (Johansson & Nilsson, 2016, p. 4). Some of the ethicists criticize the concentration on the ”trolley problem“ in describing the ethical implication of autonomous cars. It is not possible to go into this criticism any further here, in essence the argumentation is that the guidelines and parameters of the thought experiment are too narrow to be applied to road traffic and that the ”trolley problem“ attracts too much attention (cf. Goodall, 2016; Nyholm & Smids, 2016; Gogoll & Müller, 2016; Etzioni & Etzioni, 2017). From the critics’ point of view it is not necessary to wait until the ethical challenges have been fully discussed in order to bring ethically ‘correct’ autonomous cars onto the market, and there is actually no need for a moral foundation. “By also ensuring that AVs meet various structural criteria, such as effective crash zones, passenger restraints, and ‘vision’ systems for detecting pedestrians, manufacturers can create agents that minimize harm during car collisions and are therefore implicitly ethical, without designing them to have explicitly moral algorithms” (Zhao, Dimovitz, Staveland & Medsker, 2016, p. 171).

The considerations of the ethicists outlined so far are based on the assumption that the sensors of an autonomous vehicle can capture physical features or the appearance of a person very accurately extremely quick. Whether this will be technically possible in the near future is questionable. And the complexity of a (utilitarian) weighing up of the consequences of a crash is enormous. After all, it is not enough to determine the number of victims alone; it would also be necessary to weigh the level of injury risks against each other and to take into account that different groups of people have a different mortality risk in the same crash scenario. The statistical analysis of crashes has shown that drunken road users rather die than sober ones, older adults rather than younger adults, and women rather than men (cf. Goodall, 2016). Therefore, an ideal algorithm would have to be able to recognize on the one hand how many people could be affected by a crash and on the other hand also be able to identify “qualitative” characteristics of these people. It seems unrealistic that this is technically possible in the (near) future.

In a very brief summary, the literature review shows that the discussion about how an autonomous vehicle behaves ethically correct in the event of a crash and which ethical theories are best suited to program autonomously driven cars is still in its infancy. “The problem of how to program autonomous vehicles to respond to accident-scenarios is a highly complex ethical issue, under which there are various sub-issues that on their own also exhibit a lot of complexity” (Nyholm & Smids, 2016, p. 1277).

4.3 Who should decide about the ethical principles that automated cars follow? The view of the ethicists.

As discussed before, for the case of an unavoidable crash there must be a programming / algorithm in the autonomous car that ”decides” what to do. But the question arises who sets the ethical rules for the behaviour of the car? There is a discussion in the literature on ethical issues of autonomous cars about whether personal ethics setting (PES) should be permitted, i.e. the occupants of an automated car choose from the various crash algorithms before starting their journey, or whether there should be an obligatory pre-defined attitude for all of them, a mandatory ethics setting (MES) (cf. Sandberg & Bradshaw, 2013; Millar, 2014, 2016; Lin, 2014; Gogoll & Müller, 2016; Fournier, 2016; Applin, 2017; Contissa, Lagioia & Sartor, 2017; Stockburger, 2017).

The advocates of a personal ethical attitude insist that citizens only have the right to make a decision on moral issues that concern them personally. Millar (2014, 2016) argues that there must be a possibility for humans to influence the operations of autonomously acting machines that are designed to help them, otherwise they would be exposed to unethical paternalism, i.e. engineers or car manufacturers or software programmers would make unfairly ethical decisions for them and thus patronize them. The possibility of choosing one's own PES would be in accordance with the values of a liberal society. In the case of autonomous cars, this would mean that car occupants can choose from a number of pre-set algorithms. Or the driver fills out a questionnaire before starting the journey and then the car selects the appropriate ethical settings and carries out the corresponding manoeuvre in the accident situation. This means that the car manufacturer would have to offer different algorithms for selection from the outset, for example three settings (Contissa, Lagioia & Sartor, 2017):

- Egoistic mode (preference for the car occupant(s));
- Altruistic mode (preference for other road users);
- Impartial mode (depending on the situation, it will be decided whether the occupants or other road users are to be protected).

However, some ethicists are fundamentally opposed to PES. Lin (2014) describes the idea to adjust robot cars with personal ethical settings as "terrible". In his brief statement on the subject Lin points out that, on the one hand, morally problematic settings could be chosen (for instance targeting gay people over straight) and on the other hand, it would confront car users with major challenges: "the customer would still need to undergo soul-searching and philosophical studies to think carefully about which ethical code he or she can live with" (Lin, 2014, Punting Responsibility to Customers, para 1). Gogoll and Müller (2016) conclude that a MES is best for society as a whole, since allowing the occupants of an autonomous car to choose between different ethical settings would lead to socially unwanted outcomes. The Mandatory Ethic Setting (MES) would be: "Minimize the harm for all people affected!" While the consensus view seems to be that people would not be willing to use an automated car that might sacrifice themselves in a dilemma situation, Gogoll and Müller (2016) argue that such an algorithm would be nevertheless in their best interest. The reason is, simply put, that a PES regime would most likely result in a prisoner's dilemma: If you are sure that everyone else has chosen a setting to minimize harm, it would be best for you to choose a setting that only serves your protection (maximize my safety). If you are not sure what the others have chosen for a setting, you have to choose the setting "maximize my safety" again. As a result, "the expected likelihood of everyone becoming harmed actually rises" (Gogoll & Müller, 2016, p. 696).

Further criticism on the permission for PES refers to the fact that individual autonomy has its limits (e.g. when two vehicle occupants not agree on which setting to choose or legal regulations prohibit a certain setting). Applin is concerned that if ethics were adaptable in autonomous vehicles, "the road space could be more or less fragmented", depending on who drives and where (Applin, 2016, p. 110). In addition, the permission of a PES would have a serious impact on the question of liability and responsibility for the consequences of a crash: if the car occupants were able to choose the algorithm themselves, are they liable for any incorrect crash behaviour? Or is the car manufacturer liable who offers a selection of possible algorithms?

In this report it is not possible to decide whether the car passengers should have the possibility to choose between different ethical settings or whether there should be a mandatory specification for all autonomous vehicles. This requires intensive public discussion. Here too, there has to be a balance between the two ethical principles of self-determination and the greatest possible protection of humans.[22]

[22] "The problem of the programmer's decision lies in the fact that he may make the 'right' decision for a person, in accordance with the basic consensus, but that it remains an external decision (...) Consequent further thought, a person

4.4 What does the public think about how autonomous cars should be ethically programmed?

The proponents of a personal ethical setting (PES) argue that if a uniform (utilitarian) ethical setting is mandatory and strictly enforced for all autonomous cars many people could refuse to use AVs, despite the safety advantages over normal cars. A utilitarian rule could collide with the opinion of the owner or potential buyers of an AV who may consider that the safety of the occupants of an AV – and that means their own safety – should be a priority. But how would "ordinary people" behave in the described "trolley problem"-crash scenario and would they want a PES? So far, there have been a few empirical surveys on the question of what laypersons may think about the ethical rules that car drivers or autonomous cars should follow in a crash (cf. Bonnefon, Sharif & Rahwan, 2015, 2016; Li, Cho, Zhao, Ju & Malle, 2016; Frison, Wintersberger & Riener, 2016; Hohenberger, 2016; Sütfeld, Gast, König & Pipa, 2017; Faulhaber et al., 2017). The survey results are briefly presented below.

The study participants were confronted with crash-scenarios similar to the "trolley problem" described above. Participants were recruited via the Amazon Mechanical Turk platform for the studies of Bonnefon, Sharif, and Rahwan (2015, 2016), Li, Cho, Zhao, Ju, and Malle (2016) and Hohenberger (2016). The participants in these surveys received a payment. Bonnefon et al. (2015, 2016) conducted nine studies with different questions (including 402, 310, 201, 182, 451, 259, 267, 376 and 393 participants). Li et al. (2016) conducted two experiments with 120 participants each and Hohenberger (2016) conducted 2 studies with 82 and 181 participants. Frison, Wintersberger, and Riener (2016) investigated the ethical decision-making behaviour in a simulator study in which 40 people participated. 105 people took part in the study of Sütfeld, Gast, König, and Pipa (2017) and 189 in the study of Faulhaber et al. (2017). All these studies are not representative.[23]

Bonnefon et al. (2015, 2106) have investigated what humans think about two possible crash-algorithms of an autonomous car: a utilitarian (programmed to minimize a crash's death toll) and a non-utilitarian (protecting the occupants of a car). They also wanted to know whether the respondents would agree with the government dictating utilitarian algorithms and whether they would buy a car, whose accident algorithm is decided by the government. In general the participants were comfortable with utilitarian AVs (programmed to minimize the death toll), especially if the occupant of an AV is not sacrificed. When the participants were asked for the likelihood of buying a car with a utilitarian algorithm, they indicated higher likelihood of purchasing a car with a passenger-protective algorithm than a utilitarian one. "What we observe here is the classic signature of a social dilemma: People mostly agree on what should be done for the greater good of everyone, but it is in everybody's self-interest not to do it themselves" (Bonnefon, Shariff & Rahwan, 2015, p. 8). In addition, they did not agree that the government should prescribe a utilitarian algorithm.

In a commentary Martin et al. (2017) assume that the social dilemma identified by Bonnefon et al. could be caused by a lack of information and the nature of the response formulations: "We argue that the utility maximization can be increased by enabling participants to imagine themselves not only as a passenger of an AV, but also as a pedestrian" (Martin et al., 2017, p.2). Zhao, Dimovitz, Staveland, and Medsker (2016) argue similarly: "A major flaw in the experimental design of Bonnefon et al.'s study is, thus, its failure to remind survey participants that the hypothetical scenarios are (we would argue extremely) low-probability, and that utilitarian AVs are likely to predominantly protect passengers and pedestrians alike. We anticipate that including these facts would change the distribution of responses and show that worries of a social dilemma are overblown" (Zhao, Dimovitz, Staveland & Medsker, 2016, p. 172).

With their survey, Li et al. (2016) intend to find answers to the following two questions:

- "To which target will people allocate responsibility for an accident involving an autonomous car – to the producer, the owner, or the car itself?" and
- "Do people expect autonomous vehicles to take utilitarian actions when facing moral dilemmas?"

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would no longer be self-determined in existential life situations, but rather determined by others" (Ethik-Kommission, 2017, p. 16 [own translation]).

[23] With regard to the participation of men and women, it can be stated that in most studies more men than women took part. With a few exceptions, the results are not presented separately for women and men in the publications.

The results are: For the participants the car manufacturers and the government were responsible for the crash behaviour. The “utilitarian” decision to sacrifice the occupant of the car or to hit the single pedestrian (instead of five pedestrians) was considered the moral norm for both a self-driving and a human-driven car. Moreover, ethics researchers and car manufacturers / software developers were judged as having a greater obligation for deciding the moral norms for an autonomous car compared to a human driver.

In the studies of Hohenberger (2016) the participants were told, that they have to choose the ethical setting of a self-driving car and that they can change the setting after the car is parked. They should imagine that they are sitting alone in the car. The ethical settings, from which they could chose, were based on a utilitarian or deontological or self-focussed or random or law-based approach. The results are, that the participants neither do accept pre-defined self-focussed defaults nor are they accepting ethical defaults, which strictly follow the law or decide by randomness. Hohenberger concludes, that the protection of one’s own life is not a priority for the participants and that the users of autonomous cars should have the possibility to choose ethical settings by decision guidance.

Frison et al. (2016) wanted to find out how knowledge about crash risks influences driver’s decision in a crash. The participants of this driving simulator study had to decide between two options: A) Swerve and kill pedestrians; B) Provoke a crash with a randomly determined probability of himself surviving of 0 %, 25 %, 50 %, or 75 %. It turns out that even when the probability of survival was 0 % the participants refused to kill others in slightly more than half of the scenarios. If only one pedestrian would be killed, 35 % of the participants stated, that they want to save their own lives, if five pedestrians could die in the crash, only slightly over 16 % would sacrifice the pedestrians and save their own lives. Children are less likely to be sacrificed than elderly people, but the participants made no distinction between friends and strangers. Frison et al. conclude that many people would always risk their own life to rescue others, “even if we consider their survival instinct the minority of the subjects (46 %) sacrifices themselves although they know that they will definitely die (probability of survival of 0 %). This is a bit surprising as we expected most people to sacrifice the life of others when their own life will otherwise definitely end” (Frison, Wintersberger & Riener, 2016, p. 121). The participants were asked, if they would like to possess a car acting like themselves. “Subjects were not sure about that” (Frison, Wintersberger & Riener, 2016, p. 121).

In the experimental set-up of Sütfeld, Gast, König & Pipa (2017) - 105 participants were placed in a virtual car – using a Virtual Reality-headset – and drove manually along a street in a suburban area. Randomly, pairwise two obstacles appeared on the two lanes ahead of them and the participants had to decide which of the two they would save. In their rather methodological study Sütfeld et al. come to the conclusion that simple models based on one-dimensional value-of-life scales are suited to describe human ethical behaviour in such situations and “that the high contextual dependency of moral decisions and the large number of ethically relevant decisions that self-driving cars will have to make, call for ethical models based on human decisions made in comparable situations” (Sütfeld, Gast, König & Pipa, 2017, p. 12).

The design of the study of Faulhaber et al. (2017) is similar to that of Sütfeld et al. (2017). The analysis of the behaviour of 189 participants shows that the test participants acted according to a utilitarian approach and decided in favour of the (quantitative) greater good. Half of the participants were willing to sacrifice themselves to save only one other road user. “The results (…) indicate that people are still acting in favor of the quantitative greater good even when their own life is at stake“ (Faulhaber et al., 2017, p. 11).

In addition to the studies mentioned above, there is also an Internet survey on ethical issues of autonomously driven cars, but it doesn’t fulfil the scientific standards. This survey was initiated on the Robohub website, where visitors could comment on Millar’s ”tunnel problem” (a child is running onto the street and there are only two possibilities: The car is going straight and kills the child or the car swerves and kills the car passenger). The question was: If you are the passenger in an autonomous car, and you suddenly find yourself facing a tunnel problem as described above, how should the car react? (cf. Robohub, 2014) 116 people participated in the survey, 64 % of the participants said that the car should continue to drive straight and kill the child. The participants of the survey were also asked who should decide how the car should behave in case of a tunnel problem. 44 % of respondents stated that the passenger should decide how the car should response, 33 % expressed the opinion that this was the task of the lawmakers and only 12 % wanted to leave this decision to the car manufacturer.

Summarizing the results of the empirical studies gives a similarly mixed picture as in the ethicists’ discussions. There are findings in which respondents call a utilitarian approach for good, but also a selfish attitude can be found. And even those, who in principle consider an approach that follows the least possible damage to be correct, are apparently not sure whether they want to sit in a car that sacrifices the occupants to save a higher number of lives. Equally ambiguous is the situation with regard to the question of whether respondents want a PES for an autonomously driven car and who is supposed to dictate the ethical sets for the cars. Similar to the ethicists, “ordinary” people also see a tension between the ethical goals of self-determination for the individual and the greatest possible protection for all. A broader public debate and more research will be needed in the future in order to achieve more definite results.[24]

[24] Further research is needed to determine whether there are also cultural differences in the moral judgement of ethical dilemma situations. Gold et al. show in a study that there are differences between Chinese and British people regarding the assessment of the "trolley problem" (Gold, Colman & Pulford, 2014; cf. Coeckelbergh, 2016; Applin, 2017).

5 Legal implications of the introduction of automated vehicles[25]

There has been considerable progress in the development of driver assistance systems in recent years. Some representatives of the automotive industry predict that highly automated vehicles (SAE Level 4) could be launched on the market in the next five years (cf. Driverless car market watch, 2017). In order to develop and deploy highly or full automated cars into market-ready vehicles, many technical issues still have to be solved. But there are also many non-technical challenges, including legal ones.

However, the existing legislation is not (or only partially) adapted to this new type of vehicle. It is of crucial importance to find timely solutions to legal obstacles that could hinder the development and distribution of automated cars for two reasons. On the one hand, legal regulations could hinder the development of automated cars. On the other hand, the legal regulations will have a considerable influence on the extent to which automated vehicles are accepted and thus purchased by the people (cf. ITF, 2015).

BRAVE's approach is based on the assumption that the market launch of automated vehicles on public roads will only be successful if they are in line with societal values and user acceptance. As has already been noted, legal issues certainly have a major influence on the acceptance of autonomous cars by the public. Therefore, this chapter focuses on the legal implications of autonomous cars, which attract public attention or are of concern. The studies on the acceptance of autonomous cars and the population surveys on attitudes towards autonomous cars show that two legal topics are of particular interest to potential users of autonomous cars (cf. sections 2.1.3.2.2 and 2.1.3.2.4):

- Responsibility and Liability (in case of a crash) and
- Privacy / Data Protection.

As the legal situation varies from one country to another, including the states of the European Union, this chapter can only deal with the legal implications of automated and autonomous driving in a very general way. Legal questions of automated driving functions are embedded in a complex area of law (product liability law, tort law, warranty, traffic law, criminal law, insurance law, data privacy act) (cf. for Germany Hilgendorf, 2017; Oppermann & Stender-Vorwachs, 2017). For example, a distinction must be made between civil liability and criminal accountability in the event of an accident involving an automated or autonomous car (cf. Sander & Hollering, 2017). The question of liability and privacy in particular presents completely new challenges due to conditional, high and full automated vehicles. In the following, we will briefly discuss the legal situation in the countries participating in the BRAVE project and issues, the clarification of which is likely to be important from the perspective of potential users of automated or autonomous cars.[26]

[25] Due to the complexity of the topic legal implications no comprehensive database research was carried out. It would have been necessary for a large number of legal subjects to conduct searches for various countries. Despite some international agreements (like the Vienna Convention on Road Traffic and European requirements; cf. EPRS, 2016), traffic law is regulated by the individual states themselves, this is most evident from the speed restrictions that vary from country to country. The report on legal implications is based on the publication from the EU-project AdaptiVe (Bienzeisler et al., 2017) and on further English- and German-language literature focused on articles dealing with liability and privacy / data protection issues and implications in a general manner. In addition, research was carried out on the Internet in order to keep up with current legal developments.

[26] In discussing the legal implications of the autonomous driving of vehicles, we will strongly refer to a publication of the European Union-funded project "Automated Driving Applications and Technologies for Intelligent Vehicles" (AdaptiVe). As part of this project, a 250-page report "Legal aspects of automated driving" was published in July 2017, describing and discussing the legal situation in five European countries (France, Germany, Italy, Sweden and United Kingdom) and the USA (Bienzeisler et al., 2017). The AdaptiVe report also provides information on legal requirements for type approval and on insurance law, topics that are not mentioned in this report or are only touched upon in a few words (cf. for Germany additionally: Gasser et al., 2012; Kanz, Marth & von Coelln, 2012; Ebert, 2016; Lutz, 2016).

5.1 Responsibility and Liability

5.1.1 The legal situation with regard to automated vehicles

Driver Assistance Systems up to SAE-Level 2 are already included in many cars and do not pose new challenges for the law. The driver must be in control of the car at all times and must pay attention to the traffic situation. She/he is therefore also responsible and liable for the consequences of “car behaviour”. From a legal perspective, SAE-Levels 3 and 4 cars are of particular interest. They have in common that the driver is exempted from vehicle control in certain driving situations and the vehicle is controlled by its computer system in specified situations, but the extent of autonomous driving situations varies. This means that the driver is, at least in certain situations, not completely exempted from the obligation to pay attention to the traffic situation. It must therefore be legally specified whether, when and in which situations the driver is exempted from legal responsibility and liability for vehicle operation or not.

In brief, until a few years ago, the legal regulation, in terms of responsibility and liability, both internationally and in the individual countries, prescribed that the driver of a car must be a person, a human and that she/he is responsible and therefore also liable for any damage caused by the car (cf. Bradshaw, 2014; Lutz, 2016).[27] Until 2016, the worldwide framework agreement that regulates issues of traffic law – the United Nations Vienna Convention on Road Traffic, which came into force 1968 – stipulated the following: “Every driver shall at all times be able to control his vehicle” (Vienna Convention, 2015, Article 8 paragraph 5, cited in Bienzeisler et al., 2017, p. 13). This legal requirement made the introduction of automated vehicles legally impossible, since a human driver – and not a system – had to have control of the vehicle. In order to enable the legalisation of new technologies, this provision has been amended in the Vienna Agreement and in some countries, too. Automated cars are now legal, but not fully automated vehicles (cf. UNECE WP1, 2017; for details in the regulation of the Vienna Convention on road traffic and of the Economic Commission for Europe (ECE) cf. Bienzeisler et al., 2017). For the countries involved in BRAVE, the legal situation is outlined below.

5.1.1.1 Germany

In order to create legal certainty for manufacturers and users of automated driving systems, the German Bundestag has passed an amendment to the Road Traffic Act, which came into force in August 2017 (cf. Straßenverkehrsgesetz, 2017). One important change can be summarised as follows: The driver may turn his attention away from the traffic situation and vehicle operation if the car is in an automated or autonomous driving mode, but she/he must in principle remain vigilant so that he can immediately take control of the vehicle again, if necessary. This is the case when the automated system requests it or when the driver recognizes or must obviously recognize that the prerequisites for the intended use of the automation are no longer fulfilled (cf. Bundesregierung, 2017; Lange, 2017). During the period in which the automated mode controls the vehicle, the manufacturer is liable. In the pilot projects in Germany, in which fully automated vehicles are already tested on public roads, there must still be a person on board who can intervene in an emergency for legal reasons.

5.1.1.2 France

The legal situation in France until now is such that the driver must permanently be in a state and in position to execute conveniently and without any delay all manoeuvres that fall to him/her. “Each moving vehicle or moving body of vehicles must have a driver. (…) (The Highway Code) does not mention explicitly that the driver is a human being but it is highly implicit. (…) It is therefore not clear whether or not the Highway Code must be modified to allow drivers to use highly automated driving systems because, in that case, control would have to be understood as ‘supervision’ and not direct lateral and longitudinal control as it is implicitly understood now” (Bienzeisler et al. 2017, p. 43). The law allows autonomous vehicles to be tested

[27] In this respect, it would be necessary to add that in some countries, such as Germany, the owner / holder / keeper of a vehicle can also be held responsible.

on public roads, supervised by a human able to take control at any time (cf. Autonomous cars law in Europe, 2017). Autonomous vehicles without a human backup will be put to the test next year on public roads (cf. journal sentinel, 2017).

5.1.1.3 Slovenia

Šinko (2016) reports that Slovenia as most other EU countries is following the regulative which sets the driver as the one that is operating the vehicle at all times (United Nations Vienna Convention on Road Traffic and Geneva Convention Act from 1948). The legislation stipulates that, in the event of an accident involving a semi-autonomous vehicle caused by a program error, liability lies with the manufacturer. If the crash was caused by the way the vehicle was operated, the driver is responsible. In cases where this is not clear, the responsibility lies with the driver. Liability in regard to traffic accidents is regulated by 2 articles in Obligations Code Law of Slovenia (Book 1, Title II, Section 2, Subsection 5: LIABILITY FOR DAMAGE FROM DANGEROUS OBJECT OR DANGEROUS ACTIVITIES, Article 154 and Article 155; cf. List of Slovenian Laws and Regulations in English, 2017)

5.1.1.4 Spain

No specific laws have yet been adopted in Spain, and autonomous vehicles are currently subject to the general legal framework that applies to all vehicles. As Spain did not ratify the United Nations Vienna Convention on Road Traffic (1968), it was legally possible to test autonomous cars on public roads earlier than in other countries (cf. At a Glance: Autonomous Vehicles, 2017). In 2015 the legal framework for on-road testing of driverless vehicles in Spain was created (cf. Gómez-Acebo & Pombo Abogados, 2016).

5.1.1.5 Sweden

The current Swedish legislation allows testing of vehicles with a higher degree of automation on public roads, subject to authorisation by the Swedish Transport Agency. The Swedish Transport Agency stated 2014 “that there is nothing in the road traffic legislation to prevent the use of self-driving vehicles in the road transport system” (Swedish Transport Agency, 2014, p. 8).

5.1.1.6 USA

There are different legal regulations for autonomous cars in the USA, depending on the federal state (cf. Guerney, 2013; The Council of State Governments, 2016). There is no single legal framework for all aspects of autonomous vehicles in the United States, most of the traffic-related issues are regulated by the individual states. The regulatory activities of the states have increased in recent years, and the federal legislature is expanding its regulatory activities with regard to safety standards. Until November 2017 Nevada, California, Florida, Michigan, Washington, D.C., and Tennessee had already adopted legislation allowing the operation of automated cars under specific conditions (cf. Weiner & Walker-Smith, 2017), but the rules vary from state to state. The US Congress has passed a law that allows car companies to sell up to 25,000 self-driving cars without controls in the first year and up to 100,000 cars in the third year as long as the vehicles are as safe as current models with human controls (cf. Engadget, 2017).

5.1.1.7 Australia

According to the current legal situation[28], vehicles with partial or conditional automation are permitted, but the control of the vehicle still has to be clarified. “Lack of certainty relating to who or what is in control of an

[28] On the division of legislative powers between the Commonwealth Government and state and territory governments cf. Austroads & National Transport Commission, 2017, p. 2.

automated vehicle, and the concept of the driver in legislation, are the key regulatory barriers to increasingly automated vehicles” (NTC, 2016; p. 10). The barriers relate primarily to road traffic laws that implicitly require a human driver. There are currently no uniform national guidelines for testing automated or autonomous vehicles on the road (cf. NTC, 2016, p. 9).

5.1.2 Unsolved issues?

Legal regulations have been changed in most countries to enable the sale of conditionally and fully automated cars (SAE level 3 and 4) and to test fully automated cars (SAE level 5) on public roads. In essence, the legal amendments deal with the legal equality of human drivers and computers. In short, there are no legal problems with the registration of conditionally automated and highly automated cars, “if the vehicle still reserves a seating position for a human driver, and the human driver is actually able to drive the vehicle” (Bienzeisler et al., 2017, p. 91; cf. Lange, 2017). Despite the fact that SAE Level 3 and Level 4 cars have already been or will soon be legally approved – the test operation of fully automated cars without a human supervisor is regulated differently in the individual countries, for example in Germany this is not possible – the question of liability, at least for non-juridical experts, does not seem to be clearly and unambiguously regulated.[29] The following brief description of questions and scenarios selected from the literature is intended to show the complexity of the subject.

Binzeisler et al. (2017, p. 22) cite a number of questions that need to be taken into account when dealing with liability:

- What if an incident occurs while the driver was permitted to focus attention on tasks other than driving? Does it depend on the origin of the malfunction?
- What if the driver activated the system when it was not appropriate?
- What if the driver does not take over upon request by the system within the limited period of time?
- What if the system requires the driver to take over within a period of time inferior to this predetermined period of time?
- What if there is a critical situation to be handled, and the system reacts as well as the driver could have?
- What if there is a critical situation to be handled that would cause a crash if the driver were in charge, but the system does not react as well as the driver would have, and as a result, the severity of the accident is greater?
- What if the vehicle “breaks the law” when the driver is not legally required to monitor?

Sander and Hollering (2017) discuss for Germany who could be liable to prosecution in crashes involving vehicles equipped with fully automated driving systems. It would be necessary to identify when the owner / keeper of the vehicle or its manufacturer, including the design engineers and programmers employed by him, or the technical service providers who are specifically involved in the necessary data transfer, could be prosecuted under criminal and civil law. The responsible institution for the approval of automobiles may also be liable to prosecution. The owner of the vehicle may be liable for inadequate driver instruction or insufficient maintenance of the vehicle leased to the driver or for the lack of functional safety of the automated driving systems. The manufacturer may be responsible for faults in construction, fabrication and instruction. If a third party is damaged by a collision, the driver or vehicle occupant who could have taken control of the vehicle could have committed a criminal offence in addition to the aforementioned parties. This may be the case if the automated driving system is not used or if there is no or faulty monitoring and

[29] Autonomous vehicles could considerably improve safety by virtually eliminating the main source of error – the “human”. If one assumes that the implementation of autonomous vehicles would save lives, “this by itself constitutes a powerful moral reason to limit the possible responsibilities of manufacturers to a point where it does not render the development of such cars too risky for the companies involved. Of course, manufacturers should not be freed of their liability” (Hevelke & Rümelin, 2015b, p. 629). And of course, the developers and manufacturers of autonomous cars are also interested in obtaining legal certainty: “Legal uncertainty can spell the end for every critical endeavour” (Bienzeisler et al., 2017, p. 13).

oversteering or if the automated driving system is not functional. In the dilemma situations discussed in more detail in the ethics chapter (cf. chapter 4) in the case of an unavoidable accident, the car must decide which road user is to be injured or killed) the question arises as to who is liable under criminal law. Depending on the circumstances of the accident, this can be the car manufacturer as well as the vehicle owner and user.

Guerney (2013) discusses the liability of autonomous vehicles by examining product liability by using four scenarios: the distracted driver; the diminished capabilities driver; the disabled driver; and the attentive driver. Depending on the ”driver type“, there are different liability cases.

Questions of liability and responsibility touch on complex issues and they have to be answered differently depending on the different scenarios. Although in the European Union product liability is standardised by EU Commission directives, there are also differences between the individual member states. “However, there is currently no framework in place harmonising the rules on liability for damages caused by accidents in which motor vehicles are involved – the regulation of liability of the holder of a vehicle or of the driver differ between the Member States” (EPRS, 2016, p. 10). The European Commission has launched several initiatives and developed a European strategy for “connected and automated driving” but has not yet developed a proposal to further develop the legal framework for autonomous vehicles (cf. European Commission, 2016).

Other questions that have not yet been legally resolved are:

- From which level of automation on, you don’t need a driving licence to use the vehicle alone? From which level of automation on, you can use the vehicle in a state of non-roadworthiness?
- From which level of automation on can disabled people use the car alone?[30]
- May driver assistance systems overrule the car driver?
- Are people still allowed to drive fully automatic cars manually in situations for which there is an automatic mode?
- Who will be the policyholders of highly and fully automated vehicles in the future?

Many aspects of autonomous driving (SAE level 4 and 5) seem to be unclear, especially with regard to liability in the event of a crash. But even with the introduction of semi-autonomous driving cars (SAE level 3) on the market, the question of responsibility and liability for the automatic driving condition emerges and probably then the courts will have to determine the extent of liability and due diligence of the (human) driver. For instance for Germany: According to the German Road Traffic Act, a car occupant must take control if she / he recognises, “or has to recognise on the basis of obvious circumstances, that the prerequisites are no longer available for the intended use of the highly or fully automated driving functions” (Straßenvekehrsgesetz, 2017; § 1b [own translation]). But what are “obvious circumstances”?

The brief description of possible concerns about liability is intended to indicate that these ambiguities may lead to uncertainties for potential future users of automated and autonomous vehicles and thus to a decision against the purchase or use of these vehicles. “Societal acceptance of automated driving is a prerequisite to deploying such technology. Wide acceptance by customers and society cannot be expected as long as it is unclear to whom responsibility and liability will be ascribed” (Bienzeisler et al., 2017, p. 82; cf. GreyB Services, 2017).

In addition to the above-mentioned topics, two other issues discussed by the ethicists have not yet been resolved legally. The question of how an autonomous car should behave in an unavoidable accident situation where the car has to choose which road user has to be harmed (cf. the previous chapter 4.2) is legally difficult to regulate. “In view of the extremely complex and multifaceted nature of the problem and the solutions discussed, it seems almost impossible to design the programming of automated driving systems for dilemma situations in a way that is both constitutionally compliant and, moreover, satisfactory” (Sander & Hollering, 2017 [own translation]; for the USA cf. Santoni di Sio, 2017). And whether there will be a legal regulation for the question, whether the vehicle occupants of a highly or fully automated car will be allowed to choose a personal ethics setting (cf. chapter 4.3) or if there will be one ethics setting that is mandatory for all, is still completely unclear.

[30] Cf. Bradshaw-Martin & Easton, 2014.

5.2 Data Privacy

From an ethical point of view, the question also arises as to what happens with the data collected and storedby automated or autonomous vehicles, i.e. whether the right to informational self-determination is violated, or whether certain data must be passed on in order to improve the general safety of road users (cf. Ethik-Kommission, 2017; ethics commission, 2017)? This is, of course, also a legal question, since there are already many laws concerning data privacy (cf. Glancy, 2012; Boeglin, 2015; Xiong et al., 2016; Bienzeisler et al., 2017; de Cock Buning & de Bruin, 2017; Collingwood, 2017).

There is no doubt that automated cars collect a huge amount of data and the possibilities for monitoring the driving paths of autonomous cars will increase considerably with the targeted networking of autonomous cars (cf. Bienzeisler et al., 2017). With the stored data of these vehicles it is possible to determine where the drivers (frequently) move to, where they stay (longer), possibly even what they do at the locations, you can create a (movement) profile. The issue takes on a new dimension, if the automated cars are networked, then the journey can be monitored in real time.

In the European Union, data protection is now regulated throughout the Union. The general Framework "The General Regulation on personal data protection" will come into force on 25 May 2018.[31] The General Data Protection Regulation defines basic principles for the collection and processing of personal data. The Main principles are (depiction after Bienzeisler, 2017, pp. 106):

- Consent (Obtain the consent of the person before collecting or processing his/her data is required);
- Principle of proportionality (The specific purposes for which personal data are processed have to be explicit, legitimate and determined at the time of the collection of the personal data and they have to be relevant and limited to what is necessary for the purposes for which they are processed. This also implies that the period for which the personal data are stored is limited to a strict minimum);
- Principle of transparency (Information on the processing of data must be disclosed).[32]

The treatment of data collected by automated vehicles must comply with the EU directive on personal data protection. The question is whether the EU's data protection principles cover the aspects of autonomous cars. For example, laws currently require that the following data is recorded for a certain period of time: Vehicles with automated driving assistance systems will store data on whether the vehicle was steered by the driver or automatically, whether the system had to take over the driving control from the driver and whether the system malfunctioned. In the case of liability issues, it will be crucial to document the processes in the vehicle. Otherwise, it could happen that the 'driver' of a conditionally or highly automated vehicle passes on responsibility for personal failure to the manufacturer or that manufacturers try to deny technical deficiencies and impersonate driver error behaviour (for Germany cf. Bundesregierung, 2017).

With regard to the storage of data from automated cars, it does not appear to be more precisely defined for which period of time the data must be stored (the last five or ten minutes or the last hour of the car journey?) and how long these data and other data may be stored (e.g. on the driving distance and the driving time, who was the driver, what did she/he during the automatic modus?).

The question of how long data may or must be stored is connected with the question of who has access to the data.

- Can commercial companies use the data for advertising purposes (and what kind of consent by car users do they need)?
- Are authorities allowed to inspect the data (e.g. in order to punish violations of traffic rules or to investigate criminal offences)?

[31] The full name is: "Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data" (cited in Bienzeisler et al., 2017, p. 102).

[32] These three basic principles lead to the following rights for consumers: The right of information; the right of access; the right of rectification; the right to object; the right to erasure; the right to data portability.

- Is it permitted for insurance companies to access the data, e.g. in order to agree individual insurance rates?
- May car manufacturers install software updates without the consent of the car owners, e.g. to improve the system?

Of course, data or cyber security is also an important aspect of privacy / data protection, which means that car manufacturers must ensure that cars or, more generally, data stores cannot be hacked and can be abused by criminals or that the autonomous car can be impaired in its functions.[33]

If the potential users of autonomous cars do not know how much data the vehicle will generate about them and to what extent and for what purposes the data can or will be used, this uncertainty can lead to a loss of trust and thus to a fundamental refusal of even partially autonomous cars. It is therefore necessary to legislate to whom exactly the data produced by a car belongs, what the rights of consumers, manufacturers, insurers and authorities etc. are.

[33] Important questions regarding liability would also arise on this issue (cf. Douma & Aue Palodichuk, 2012).

6 Social and economic implications of automated vehicles

Automated vehicles hold the potential to revolutionize the transport system. Less crashes, increased capacity, improved fuel efficiency, and reduced parking demand in urban environments are just some of the potential benefits that could come with automated vehicles. However, changed travel behaviour and economic incentives might lead to increased travelling by private vehicles, causing negative externalities such as increased congestion and emissions. The social and economic impacts will likely affect whether society will accept automated vehicles or not. It is therefore important to understand the potential social and economic impacts of implementing automated vehicles on the market in order to guarantee safety and ensure the needs of users and stakeholders.

The following chapter is based on the findings and discussions of 21 studies covering social and economic impacts of automated vehicles.[34] When looking at these previous studies it becomes clear that some topics are of particular interest. Relevant findings are therefore discussed in detail under these topics in the following literature review.

It is important to mention that while some of the potential social and economic impacts described below come already at conditional automation (SAE level 3), others require high or full automation (SAE level 4 or 5) where no driver need to be ready to take over the driving task. Most of the following studies cover fully autonomous vehicles which are not yet available on the market. Thus, many of the scenarios described below are still hypothetical.

6.1 Car sharing

Autonomous vehicles will likely facilitate the implementation of car sharing systems operating on demand and allowing passengers to share the same ride with only minimal increases in travel time. Car sharing services including non-autonomous vehicles, like Car2Go, DriveNow or eMov, are growing rapidly in big metropolitan areas, providing a cheap, fast and traffic-friendly alternative to private vehicles.

It is hoped that the technology of autonomous vehicles will be able to deal with some of the challenges of today's car and ride sharing programs, such as limited reliability and accessibility (cf. Zhang et al., 2015). Alessandrini et al. (2015) describe a future vision where travellers in cities would be able to use smart cards or smart phones with their contract information to access shared automated vehicles either parked nearby or by ordering a vehicle on-demand for door-to-door service. In this scenario, users would be free of the stress of finding free parking spaces in cities as they could just leave the automated vehicles along the street to let them park themselves at the nearest parking spaces or depots. Further, time and mileage for the effective use of the vehicles could be automatically charged from the users' smart cards or smart phones. Thus, with a developed system of shared automated vehicles, the convenience of a publicly owned and maintained vehicle fleet could be combined with the benefits of owning a private car, such as flexibility and door-to-door service (cf. Alessandrini et al., 2015). Automated vehicles thereby have the potential to create new business models of mobility (cf. Wadud, MacKenzie, & Leiby, 2016).

The discussion in the literature makes it clear that whether automated vehicles will be shared or not play an important role for the social and economic impacts we can expect from automation. Therefore, several of the following topics will be discussed in the light of how car sharing systems might affect the expected impacts of automated vehicles compared to private vehicle ownership. However, it should be mentioned that the full benefits of a system of shared automated vehicles will not be realized until the automated systems operate highly or fully automated (SAE level 4 or 5) where no drivers need to be prepared to intervene.

[34] Research databases Science Direct and Scopus were used to search for peer-reviewed journal articles. Search words were autonomous car, autonomous vehicles, non-drivers, and driverless vehicles, which were paired with words related to economic and social aspects, including market penetration, labour market, and mobility. In the 15 articles found, the lists of references were used to find more literature on the economic impacts of autonomous vehicles. Six more articles were used, including literature that is not peer-reviewed.

6.2 A more equal transport system?

With the adoption of fully autonomous vehicles (SAE level 5) comes the possibility to provide a more equitable and socially inclusive transport system (cf. Ohnemus & Perl, 2016). Possibilities for persons with reduced mobility (PRM) including older people, non-drivers, or those with disabilities to use cars is one of the commonly mentioned social impacts of fully autonomous vehicles (cf. Alessandrini et al., 2015; Harper et al., 2016; Litman, 2017; Meyer et al., 2017; Ohnemus & Perl, 2016; Smith, 2013; Wadud, MacKenzie, & Leiby, 2016). Today, PRM lack of travelling independence and their mobility is often dependent on family, friends, government and other providers (cf. Harper et al., 2016). However, with automated vehicles, increased mobility and traveling for non-drivers would be possible. Alessandrini et al. (2015) argue that automatic driving would not only give older people or those with disabilities the opportunity to use cars, but also offer them better riding comfort due to smoother acceleration and jerk. According to Litman (2017) independent mobility for non-drivers might begin already in the 2020s or 2030s.

If car sharing systems are implemented, automated vehicles could also contribute to a more inclusive society. With a shared system of automated cars, it would be possible for users to only pay for their actual use of the vehicles, which would be more economical than privately owned automated cars (cf. Alessandrini et al., 2015). Thus, according to Alessandrini et al. (2015) shared automated vehicles could provide easily accessible and low-cost mobility for low-income people. Levin et al. (2017) further argue that these car sharing services could replace the need for personal vehicles as low-cost traveling would be provided for the citizens. However, Litman (2017) argues that additional costs related to empty repositioning trips, cleaning, reduced service, and less privacy may lead to people still choosing private vehicles over shared autonomous cars. Further independent mobility for low-income people will not be significant until automated vehicles are common and affordable, which will likely not happen until the 2040s to 2060s (Litman, 2017).

6.3 Travel behaviour and travel demand effects

Implementation of automated vehicles will likely have effects on travel behaviour, both in the way of how much we travel, and in what way we travel. Litman (2017) argues that increased travel comfort, convenience, and possibilities for non-drivers to use cars could cause an increase in vehicle miles travelled. Wadud, MacKenzie and Leiby (2016) further argue that automated vehicles might lead to increased travelling because of reductions in generalized travel costs. For example, insurance costs might decrease due to reduced crashes, and fuel costs might decrease due to more efficient driving. Further, drivers will be able to use their time in the car to other activities than driving which reduce the costs of in-vehicle time. Thus, Wadud, MacKenzie and Leiby (2016) suggest that policies with the aim to control increases in vehicle miles travelled and congestion might be more important with automated vehicles than with regular vehicles. They argue that this would be especially important if the energy use per kilometre fall with automation, since energy based taxes would be less effective in controlling travelling. Smith (2013) further argues that travelling might increase substantially due to the increased mobility for people who currently cannot legally drive themselves. Harper et al. (2016) estimate bounds on how automated vehicles will increase the vehicle miles travelled for the non-driving and elderly populations and people with travel-restrictive medical conditions. According to their results, vehicle miles travelled for light duty vehicles would increase by 14 % in the US if the adoption of automated vehicles could give these populations the possibility to use cars (cf. Harper et al., 2016).

According to Meyer et al. (2017) a modal shift towards new services, such as the shared autonomous vehicles previously discussed, might be expected as prices, convenience, and comfort will make them highly competitive to privately owned cars and public transit. Fagnant & Kockelman (2015) argue that with car and ride sharing programs serving travellers on demand, more vehicle miles would probably be travelled, however with less vehicles and parking places needed. Litman (2017) also discusses the importance of car sharing in means of whether automation will result in increased or decreased travelling. Even though improved convenience, comfort and access might result in increased travelling, a car sharing system might decrease total travelling due to reduced car ownership. Harper et al. (2016) argue that vehicle automation in general will likely lead to increased vehicle miles travelled due to the possibility for underserved populations to travel more. However, with ride sharing systems, automation could instead decrease the vehicle miles travelled.

Krueger, Rashidi and Rose (2016) conducted a stated choice survey to identify which users would likely adopt shared autonomous vehicles, and to investigate the willingness to pay for different services. They find that young respondents are more likely to choose shared autonomous vehicles with dynamic ride sharing. Further, those that usually travel by car as drivers were more likely to select shared autonomous vehicles without dynamic ride sharing, while respondents who usually travel by car as passengers were more likely to choose the option with dynamic ride sharing. Travel cost, travel time and waiting time turn out to be important determinants of the use and acceptance of shared autonomous vehicles and dynamic ride sharing. Those dynamic ride sharing services seems to be an intermediate alternative to car sharing and public transport usage in terms of global efficiency and user costs.

Rakotonirainy, Schroeter, and Soro (2014) present visions on how vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication can improve drivers' behaviour in a scenario of partially automated vehicles where drivers still have the main control over the car. By sharing information between vehicles, such as historical data on average speed in school zones, the authors argue that social norms and self-efficacy might develop better driving behaviour. Social networks in the driving context could thereby lead to moral values and driving behaviour that promote safety, greener driving, reduced aggressiveness and reduced risk taking.

6.4 Safety

Many car crashes occur because of distracted drivers or human error. According to Fagnant and Kockelman (2015) over 40 % of fatal crashes in the US involve alcohol, drugs, distraction, and/or fatigue. Furthermore, driver error is believed to be the main reason behind more than 90 % of all crashes in the US (cf. Fagnant & Kockelman, 2015). With automated vehicles, the risk factor of human behaviour such as distracted driving will be eliminated, and the vehicles will be able to collect and react on real time information (cf. Winston & Mannering, 2014). Thus, with automated vehicles, more traffic accidents can be avoided, which will lead to reduced costs and fatality (cf. Fagnant & Kockelman, 2015; Harper, Hendrickson, & Samaras, 2016; Winston & Mannering, 2014). Fagnant and Kockelman (2015) estimate traveller benefits of automation across different levels of market penetration. At the 90 % market penetration level, automated vehicles are assumed to reduce crash and injury rates by 90 %. They estimate crash costs both based on the economic consequences as well as on the comprehensive costs which include pain, suffering and the value of a statistical life. Their estimations show that the annual economic cost savings per automated vehicle would be $960 at the 90 % market penetration level, while the annual comprehensive cost savings per automated vehicle would reach $3100 at the same market penetration level. Harper, Hendrickson and Samaras (2016) evaluate the costs and benefits of implementing three partially automated crash avoidance technologies, namely blind spot monitoring, lane departure warning and forward collision warning. They calculate lower and upper bound fleet-wide benefits and find that annual net benefits from adopting the three technologies will range between $4 billion to $202 billion in the US, where the upper bound calculations assume that all relevant crashes can be avoided. However, several new risks may appear with automation that can reduce the expected cost savings related to the adoption of automated vehicles (cf. Litman, 2017). If autonomous technology manages to improve safety there is a risk that users perceive a false sense of immunity from injury (cf. Harper, Hendrickson and Samaras, 2016). This could for example result in a reduced use of seat belts or increase user distractions. Further, system failure of the automated vehicles, additional risk taking from road users, and safety issues related to a mixed traffic where drivers share the road with automated vehicles might come with automation (cf. Litman, 2017).

6.5 Efficiency

Several papers mention improved efficiency of the transport system as one of the positive economic impacts of automated vehicles (cf. Alessandrini et al., 2015; Ohnemus & Perl, 2016; Shi & Prevedouros, 2016; Wadud, 2017; van den Berg & Verhoef, 2016; Crayton & Meier, 2017). Van den Berg and Verhoef (2016) describe that autonomous cars will be able to safely drive closer together than human driven cars and thereby increase road capacity. Ohmneus and Perl (2016) further state that efficiency will increase due to higher road capacity and the possibility to use the driving time for work or entertainment. Shi and Prevedouros (2016) find that with V2V and V2I communications it will be possible to obtain a more efficient traffic flow, especially in freeway weaving sections. Moreover, automated vehicles are expected to use existing lanes more efficiently by driving with shorter distances between the vehicles or in coordinated platoons, and by making better route choices (cf. Fagnant & Kockelman, 2015). Nevertheless, according to Shi & Prevedouros (2016) it is unlikely that any positive traffic flow externalities will be achieved with shares of driverless cars below two percent. Winston & Mannering (2014) argue that not only would automated vehicles create smoother traffic flow, reduce delays and efficiently route drivers according to real-time information, but they would also leapfrog other existing technologies that could improve the efficiency of highway pricing, investment and operations.

6.6 Congestion

One widely discussed economic impact of automation is whether congestion will increase or decrease. According to Fagnant and Kockelman (2015) automated vehicles could be able to reduce congestion due to technological innovations. For example, automated vehicles will be able to sense when the lead vehicles are braking or accelerating and thereby smoothly adjust their speed accordingly. Further, the automated vehicles could more efficiently utilize green time at traffic signals due to shorter headways between vehicles and shorter start-up times, which would improve intersection capacities (cf. Fagnant and kockelman, 2015). Shi and Prevedouros (2016) further argue that traffic flow perturbations could be reduced due to advanced settings, such as adaptive headways, of the driverless vehicles. Alessandrini et al. (2015) describe a preliminary vision of the future with automated vehicles and argue that congestion could be reduced because of more efficient driving and avoidance of traffic accidents. Using a dynamic equilibrium model of congestion, van den Berg and Verhoef (2016) find that an increased share of autonomous cars will lead to increased road capacity and thereby decreased congestion externalities. However, as people can use their time in the autonomous cars to other activities than driving, the value of travel time losses (VOT) may be reduced. As congestion decrease along with a rising VOT, switching to autonomous cars might therefore also cause negative externalities as people increase their traveling. Thus, the implementation of autonomous cars can either result in increased or decreased congestion, and will largely depend on if people increase their travelling or not. According to the numerical analyses put forward by van den Berg and Verhoef (2016) net positive externalities are most likely. In contrast, Levin et al. (2017) use a traffic flow model and find that, without a dynamic ride sharing system, shared autonomous vehicles will increase congestion because of the additional empty repositioning trips that the vehicles will have to drive.

Although automation may come with several congestion reducing improvements, Fagnant and Kockelman (2015) add that many of these will depend on cooperative abilities such as V2V and V2I communication, and not only on the automation itself. Further, Alessandrini et al. (2015) argue that most positive impacts of automation, such as congestion saving improvements, will come from the development of car sharing. With a car sharing system of automated vehicles, individual car ownership will likely decrease and thereby reduce congestion (cf. Ohmneus & Perl, 2016). Additionally, a system of shared automated vehicles will impose positive externalities as congestion related to finding free parking spaces in city centres can be avoided (cf. Alessandrini et al., 2015).

6.7 Environment

Mitigating the harms of climate change and limiting the effects of air pollution on public health is today a global top priority. Since road transport currently accounts for a significant part of global emissions, it is important to consider the possible impacts of autonomous vehicles on environmental health (cf. Crayton & Meier, 2017). The adoption of automated vehicles will likely affect emissions in a number of ways, which may both be positive and negative (cf. Wadud, MacKenzie, & Leiby, 2016). Eco-driving and platooning are characteristics of automated vehicles that could directly reduce emissions. However, if automated vehicles will have net positive or negative effects on emissions will not only depend on the vehicle itself, but on how we use them. Wadud, MacKenzie and Leiby (2016) argue that changed demand and vehicle operating profiles are factors other than those related to for example the vehicle design and fuel choice that will affect emissions. They argue that depending on which effects that will come to dominate, emissions from road transport could either be reduced by half, or nearly doubled. Crayton and Meier (2017) discuss the possible environmental consequences of automation and highlight the importance of, for example, fuel efficiency, reduced private car ownership, and the avoidance of traffic congestion in order to reduce emissions. They argue that whether emissions will increase, or decrease will depend on factors such as the characteristics of the autonomous vehicles, consumer preference related to private car ownership, and how the transport system will adapt to the vehicles. As previously discussed, several factors point towards increases in travelling by private cars, while other articles argue for increased travelling by car sharing systems. Because of great uncertainty regarding technical, behavioural and regulatory changes Wadud, MacKenzie and Leiby (2016) mean that predictions regarding the precise impacts of automation on emissions from road transport are hard to estimate.

6.8 Parking

Automated vehicles can have positive effects on urban environments due to a decreased demand for parking (cf. Alessandrini et al., 2015; Zhang et al., 2015). With a shared autonomous vehicle system operating on demand and allowing passengers to share the same ride, vehicles can serve more passengers and reduce parking demand as they automatically relocate to places from where trips will start (cf. Zhang et al., 2015). Zhang et al. (2015) estimate the impact of a shared autonomous vehicle system on demand for parking in urban areas under different scenarios. They find that parking demand will be sensitive to the number of shared autonomous vehicles in the system and the willingness to share rides among users. According to the simulation results, up to 90 % of parking demand for the studied households could be eliminated with a system of shared cars and additionally one percentage point if ride sharing services were added to the system (cf. Zhang et al., 2015). Further, by allowing five minutes cruising time for the shared vehicles, parking demand would be reduced by additionally two percentage points. Alessandrini et al. (2015) also argue that not only would shared automated vehicles reduce parking demand by a decrease in the number of vehicles, but also reduce the space required for parking each one of them. Moreover, autonomous vehicles could lead to a relocation of parking places as they would be able to move themselves to different locations after dropping of a passenger. Users would be able to leave the vehicle on the street and let it park on its own at a depot or car park, which do not necessarily need to be situated in the city centre, before moving to pick up another user on demand. Thus, with a system of shared autonomous vehicles, less space in urban areas will be needed for parking. These areas can instead be used for greener and more human oriented places (cf. Zhang et al., 2015), and to improve life in urban environments by for example more space for pedestrians and bicycles (cf. Alessandrini et al., 2015).

6.9 Public transit

Meyer et al. (2017) simulate the impact of autonomous vehicles on accessibility in Switzerland and conclude that in general, a fleet of shared autonomous vehicles will be able to serve the full motorized travel demand and still reduce travel times. Only in larger cities will public transport still be needed as increased transport demand will outweigh the increases in capacity that comes from automation and thereby cause increased travel times. According to Meyer et al. (2017) public transit might therefore be reduced to operate only in centres of large agglomerations where transport demand is highest. In smaller cities and rural areas, fleets of autonomous vehicles will likely serve the full transport demand as it is expected to be cheaper, faster and more comfortable than public transit. Bösch et al. (2017) use a comprehensive analysis of cost structures and find that public transport, as it works today, will only be able to compete with autonomous vehicles in areas where the demand requires larger units. Thus, in accordance with Meyer et al. (2017), Bösch et al. (2017) argue that public transport will likely only operate in dense urban areas where it can be offered at lower prices than autonomous cars and taxis. In other areas, car sharing systems will be able to serve the total transport demand. However, Bösch et al. (2017) argue that a large share of vehicles will still be privately owned due to various benefits of owning a private car. Even higher fixed costs than for private cars today are likely to be accepted by the owners for these private autonomous vehicles.

6.10 Employment

The adoption of automated vehicles is expected to come with several important benefits for the transport system. Cost savings due to reduced driving costs have been identified in the literature of automation. Winston & Mannering (2014) argue that driverless trucks would contribute to the industry by greatly reducing labour costs and operating costs. Wadud (2017) perform a total cost of ownership analyses and conclude that commercial operations (taxi and truck) benefit significantly more from automation than private users as the driving costs can be substantially reduced. However, the benefits of the automated vehicles may come at the expense of employment for several common professions in the world. Driverless vehicles will result in a reduced need for workers employed in driving. Crayton and Meier (2017) discuss the relationship between technological innovations in the transport sector and public health. They argue that even though autonomous vehicles might improve efficiency, decrease congestion, save travel time and lower costs, it could cause unemployment for millions of people employed within transport.

6.11 Public opinion on social and economic impacts

Bansal, Kockelman and Singh (2016) conducted an internet based survey in Austin (Texas, United States) regarding opinion and adaption to smart-car technologies. They find that more than 80 percent of the respondents are interested in owning an automated vehicle. The results indicate that less traffic accidents are considered to be the most likely benefit of automated vehicles among respondents, while decreased congestion is believed to be the least likely. The top concern among the respondents is equipment failure of the vehicles. When studying different pricing scenarios, it is found that respondents on average are not willing to pay more to use shared autonomous vehicles than they currently pay for services from UberX and Lyft, which is about $1.50 per mile. Bansal, Kockelman and Singh (2016) further analyse the results regarding respondents' decisions to shift their home location as autonomous vehicles and shared autonomous vehicles become more common. They find that respondents with more children who drive alone to their work and live farther from their workplace are more likely to move even farther away from Austin. Moreover, people living in high household density neighbourhoods having at least a bachelor's degree are also more likely to shift farther from Austin. Instead, high income, full time working males with higher vehicle miles travelled are more likely to move closer to Austin. Those results clearly reflect the increase of transport usage when having access to autonomous vehicles.

7 Conclusions[35]

The acceptance of AVs in the perspective of road users

The objective of the present chapter was to give a short overview on definitions and theoretical approaches to acceptance. As seen, there is no universal, valid definition to acceptance nor a single approach, but a broad range of theoretical constructs. These are more or less specific (depending on the degree of specification regarding a concrete, existing product), so that it still is not certain which model fits best with the objectives of BRAVE. Knowing that the model of acceptance of driver assistance systems by Arndt (2011) or the model adapted to driverless vehicle technologies by Kelkel (2015) concretely refer to systems that can assist the driver or fully take over the driving task, other approaches, like the TAM or the UTAUT refer to technology in general. However it can be emphasized that those approaches are powerful and widespread tools of which the suitability for BRAVE can be assumed.

To resume relevant implications regarding the acceptance of automated vehicles it was shown that there are not many studies or surveys concretely referring to the acceptance of automated driving level 3 as defined by SAE J3060. This can on one hand be related to the finding, that within the reviewed studies acceptance was not clearly defined, on the other hand they did not always refer to a concrete classification of vehicle automation. Mainly the expressions manual driving, partially automated driving, highly automated driving and fully automated driving were used. The common point among the studies was that they assessed the public perception and attitudes towards characteristics of highly / fully automated vehicles that might impact on the intention to use or the intention to purchase automated vehicles.

The studies all referred to safety aspects, knowing that expectations are rather positive regarding the accident reduction potential, however remain somewhat critical when the idea of technical failure is brought up. Fears related to system failure seem to be present and need to be taken into account when BRAVE systems are launched. Worries regarding system failure can also be related to trust problems. The comfort that passengers of highly / fully automated vehicles expect or what secondary task they engage in might depend on their tendency to trust machines. The literature review shows that the general level of trust in machine driving is limited. In this context, it was reported that within the reviewed studies the majority of participants were concerned that self-driving vehicles cannot drive as well as human drivers. The influence of trust was also present in the way participants planned to spend their time. When they had the possibility to choose between engaging in secondary tasks or paying attention to their environment / the traffic situation a remarkable proportion preferred to stay vigilant to the traffic. Other implications important for the focus of BRAVVE can be related to worries about data privacy and liability. As it is not clear yet who will be liable in what situation and who will have the right to access the data gathered with the introduction of automated driving on European roads, the uncertainty was found to be a concern to European citizens.

Research findings clearly illustrate that males and females have distinct perceptions, expectations and concerns towards automated / autonomous vehicles. The finding of the described surveys suggest that men generally have more positive expectations regarding automated features / driver assistance systems in cars and also seem to be slightly more willing to buy such systems than females and that the attitude of females towards automated / autonomous vehicles is rather reserved. It is suggested that the female population knows less about and is less interested in these automated / autonomous car technology. They express more doubts about the safety of self-driving systems and a higher tendency to mistrust in such systems driving. They are less concerned by the risk of losing driving enjoyment and have other ideas than males regarding how to spend their time within self-driving vehicles.

The evidence presented in this report suggests that the most efficient way to address women's reticence towards automated/autonomous vehicles would be to address safety concerns and transfer knowledge to provide trust in the safety of these new types of cars. In order to build confidence in the crash-reducing nature of self-driving technology an efficient (gender-sensitive) marketing strategy could outline the general functioning of self-driving technology and the safety-relevant features.

[35] The respective authors of the chapters or sections in the text are also responsible for the following conclusions of their text part.

To reach a high level of acceptance, it can be assumed that further research is required in order to learn more about concerns and to build solutions that take into account the needs and worries of European citizens. This research and the planned representative survey performed within WP2 of BRAVE should systematically consider gender aspects. This survey could be based on already existing acceptance models.

The acceptance of AVs in the perspective of organised stakeholders

In the scientific literature management of expectations between stakeholders, different time horizons for implementation, but also impacts on strategic decision making and its effect on e.g. traffic flow and safety emerged as key findings. Although the scientific literature was scarce it indicated that there is a need for different stakeholders to address challenges jointly. The position papers, which reflect stakeholder views of member organisations, show that there are joint efforts and collaboration between stakeholders on the subject of AVs. In general, the position papers address AVs in terms of an ongoing technological development, or as stated in the position paper by ERTRAC (2017) "the long-term evolution of the Transport System" (p. 36). A common issue that is addressed in all the reviewed position papers concerns legal aspects.

Road safety implications of the implementation of automated vehicles in real-life traffic

This SoA on autonomous vehicles and road safety reveal that the role of the driver is changing, both qualitatively and quantitatively. It should be noted that SAE levels 2 and 3 are presented in the respective chapter. On a general level, a human driver's manoeuvres and actions, when driving in autonomous modes, are not as safe compared to manual driving. The results on a number of road safety issues revealed that autonomous driving behaviour have a long way ahead in terms of road safety. This is due to several traditional HMI concerns, such as transfer of control, attention, trust and situation awareness. Humans are not well suited for supervision tasks and therefore easily lose track of the situation at hand and intervene less well compared to being in control at all times. The kind of problems or issues found with autonomous vehicle-functions at SAE levels 2-3 are very different to the highest levels, SAE level 4 and 5, these are, however, not discussed here.

An overall summery could be expressed accordingly. Autonomous cars on the SAE level 2 and level 3 of automation are overshadowed by several issues that are problematic from a road safety perspective. In the Kyridikadis et. al. (2017) article several predicted problems were discussed.

Firstly, the different role given to the driver using AV. The task to perform is different and history has shown us that technological (as well as other changes on a macro level) also change the way people behave and act. Hence, there is a qualitative difference in the role (to supervise a system compared to control all aspects of driving and be in command at all times) as a driver.

Secondly, there is also a quantitative difference in behaviour and performance. When the focus is to measure reaction times or braking pressure, eye-moments etc. most often results reveal that automation levels 2 and 3 is problematic from a road safety perspective. People seem to react slower, do not detect hazards, and end up in more critical situations more often in autonomous cars. These findings seem to be correct as far as we know today based on the small data points that have been reported when it comes to accidents. Autonomous cars are over represented in the traffic accident studies performed.

Traditional human-computer-interaction (HMI) concepts such as transfer of control (TOC), mental workload (MWL), situational Awareness (SA) and trust are discussed. It is shown that the driver finds it difficult to understand the situational context when requested to take over. If this is due to being out-of-the-loop, or reduced SA or a big variation in mental workload, is hard to tell given the current SOA.

How drivers experience information feed-back, system failure and develop trust also follow the developments of other technological changes. Feedback needs to be expressed in *how* and *what* terms. System failures are difficult to detect, especially partial system failures and trust is developed over time (and is not well calibrated with reality).

Other aspects are considered as well in the respective chapter. A new driver model is expressed as well as the driver-system unit. New methods are developed in order to be able to answer the new research questions generated by this psychological shift, the driver is not controlling either longitudinal or lateral movement since the driver no longer has to hold the steering wheel.

The road safety literature suggests a problematic pattern of issues. These concerns or issues will need to be considered if potential increases in road safety from AV are to be realised. The literature also suggests that there is a potential for improved road safety, as long as driver behavioural adaptation such as drivers engaging in non-related driving tasks can be mitigated.

An important caveat for this SoA is that it has a very short shelf-life. Scientific articles in the field of road safety and AV is a burgeoning area and extremely current. In the short interval between the literature search and the writing of this chapter, more articles are being published.

Ethical implications of the introduction of automated vehicles

The literature review showed that for some years now there has been a discussion about the ethical implications of autonomous driving, but this discussion has mainly focused on the "trolley problem", i.e. the crash behaviour of autonomous cars in a situation that is rarely encountered in reality. Most of the authors who raise ethical questions insist that in the future autonomous cars must make decisions that touch on ethical issues and that these ethical issues have not yet been sufficiently and transparently discussed. But the way autonomous vehicles are programmed will determine their societal acceptance. This places a considerable responsibility on the programmers and designers of automated vehicles to design ethically and socially acceptable vehicles.

In this report, it is not possible to answer the question of how an autonomous car should behave in the event of an unavoidable crash in a scenario which is similar to the "trolley problem". Neither is it possible to decide what would be the most appropriate ethical approaches for the programming of autonomous cars – there is no consensus on this in the literature – and if there should be the possibility of Personal Ethics Settings for the users of automated cars. If ethics settings in autonomous vehicles could be adapted to the wishes of car occupants, this could lead to very different road traffic conditions, depending on who is driving with which ethical setting.

The few empirical studies on how the public thinks about the ethics settings of autonomous cars also show no clear result. There seems to be an acceptance that a car should be programmed in such a way that, in the event of a crash, as little human harm as possible occurs, but it is not clear whether many people would be willing to purchase or use a car, which sacrifices the car occupant to save someone else’s life. Perhaps further surveys, which are representative for a country in their sample of participants, can provide more clarity. Assuming that the success of autonomous automobiles must met with the (moral) acceptance of broad sections of the population, it would also be necessary to gain more insight into their attitudes towards ethical issues.

What is evident from the literature review is that it is essential to clarify a number of important ethical and legal questions before the market launch of autonomous cars:

- Who determines the ethical programming of autonomous cars?
- Can car occupants have a personal ethical setting? If so, where are the limits of an egoistic mode?
- Is a human driver allowed to take control even though the car can also drive automatically (and better)?

The remaining issues to be clarified should not only be discussed by ethicists and automobile representatives, but as far as possible by the general public so that the necessary decisions on how an autonomous car will be ethically programmed are transparent and comprehensible for the public and future users of an autonomous car. This is also important because rules have to be drawn up here, which have to balance between the two socially important ethical principles of self-determination and safety.

In order to make the discussion public, ethics committees could be set up, as has happened in Germany. Another solution to create transparency could be the implementation of institutional review boards, which would oblige the manufacturers of autonomous cars to explain why they want to select specific crash scenarios.

Legal implications of the introduction of automated vehicles

The brief overview of the legal implications of autonomous cars shows that in many countries legislation is now reacting to the new technology. Nevertheless, many aspects and topics are not yet regulated by law, at least this could be the impression for the legal layman. The issues of liability – who is liable in which case for a crash – and privacy – who has access to the data collected by the automated car – should be regulated comprehensibly and transparent for the ordinary consumer in order to make the market launch of automated cars a success.

Social and economic implications of the introduction of automated vehicles

The literature review has shown that social and economic impacts of automated vehicles have been studied and discussed from several different perspectives during the last few years. According to the findings from previous studies, automated vehicles have several clear benefits that might change the entire transport system. The technological advantages of automated vehicles have the potential to reduce crashes, increase fuel efficiency, reduce parking demand, improve road capacity, ease congestion, and increase mobility for non-drivers. However, with mass penetration of autonomous vehicles, travel behaviour might change and have large effects on the expected social and economic impacts of automated vehicles. Several of the articles argue that most positive impacts of automated vehicles will come from the development of cooperative behaviours, such as car and ride sharing systems, as these would reduce individual car ownership. However, several factors point towards increases in travelling by private vehicles, which could instead lead to negative externalities such as increased congestion and environmental degradation. For example, opportunities for non-drivers to use cars, possibilities to use the time in the car to other activities than driving, reductions in generalized travel costs, and increased convenience will likely increase the attractiveness of travelling by private vehicles. Thus, the positive externalities that come from the technological advantages of automated vehicles might be outweighed by the negative externalities coming from the potential increases in travelling by private vehicles. It becomes clear that whether automated vehicles will come with net positive or negative externalities will depend on which effect that comes to dominate. The great uncertainty regarding how people will change their travel behaviour makes it hard to draw any clear conclusions regarding the social and economic impacts of automated vehicles. Thus, it is important to further investigate the possible behavioural changes that might come from the implementation of autonomous vehicles, since they will play an important role for the social and economic impacts of automated vehicles.

Another important issue that needs to be further discussed before automated vehicles are launched on the market is how to handle the effects on employment. Even though automated vehicles will come with several benefits for the transport sector, such as reduced operational costs for several transport industries, it might come at the expense of employment for millions of people employed within driving.

In order to maximize the benefits of automated vehicles and minimize the negative effects, policy makers should consider early actions to mitigate potential negative consequences. Future research should investigate how policies can be used to control potential increases in travelling by private vehicles, and how to increase the attractiveness of car sharing systems. Studies that improve our understanding of individual responses to automated vehicles are extra beneficial due to the behavioural uncertainties in previous literature. To ensure the full benefits of automated vehicles further evaluation, analysis and policymaking is needed.

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