Grant Agreement Number: 731993

Project acronym: AUTOPILOT

Project full title: AUTOmated driving Progressed by Internet Of Things

D.4.6

Quality of Life Impact Assessment

Due delivery date: 31.12.2019

Actual delivery date: 31.12.2019

Resubmission date: 16.03.2020

Organization name of lead participant for this deliverable: VTT

Dissemination level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential , only for members of the consortium (including the Commission Services)	

Document Control Sheet

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 731993.

Deliverable number:	D4.6
Deliverable responsible:	VTT
Work package:	WP4
Editor:	Elina Aittoniemi, VTT

Author(s) – in alphabetical order		
Name	**Organisation**	**E-mail**
Elina Aittoniemi	VTT	elina.aittoniemi@vtt.fi
Yvonne Barnard	University of Leeds	y.barnard@leeds.ac.uk
Gillian Harrison	University of Leeds	g.harrison@leeds.ac.uk
Daniel de Klein	City of Helmond	d.de.klein@helmond.nl
Viktoriya Kolarova	DLR	viktoriya.kolarova@dlr.de
Esko Lehtonen	VTT	esko.lehtonen@vtt.fi
Fanny Malin	VTT	fanny.malin@vtt.fi
Lara Naendrup-Poell	DLR	lara.naendrup-poell@dlr.de
Pirkko Rämä	VTT	pirkko.rama@vtt.fi
Katerina Touliou	CERTH	touliouk@certh.gr

Document Revision History			
Version	**Date**	**Modifications Introduced**	
		Modification Reason	**Modified by**
V0.1		First Draft	Elina Aittoniemi (VTT)
V0.2		Second draft	Elina Aittoniemi (VTT)
V1.0	20/12/2019	Peer reviewed release	Elina Aittoniemi (VTT)
V1.0	20/12/2019	Peer reviewed release	Francois Fischer (ERTICO)
V1.1	10/03/2020	Formatting changes	Rita Bhandari (ERTICO)

Abstract
This document presents the results of societal quality of life assessment in the AUTOPILOT project.

Legal Disclaimer

Abbreviations and Acronyms

Acronym	Definition
AD	Automated driving
ADAS	Advanced driver assistance system(s)
AV	Automated vehicle
AVP	Automated valet parking
CAD	Connected and automated driving
CAV	Connected and automated vehicle
EC	European Commission
GA	Grant Agreement
HAV	Highly automated vehicle (SAE L4/L5)
IoT	Internet of Things
ODD	Operational design domain
PO	Project officer
QoL	Quality of life
SD model	System dynamic model
V2I	Vehicle to infrastructure communication
V2V	Vehicle to vehicle communication
VKT	Vehicle kilometres travelled
VRU	Vulnerable road user
WP	Work Package

Table of Contents

List of Figures

List of Tables

Executive Summary

This report presents the results the Quality of Life impact assessment in the AUTOPILOT project. It describes the quality of life impacts as well as the methodology used to assess them. Quality of life impacts are defined in this context as the potential implications on health, well-being, and equity, reflected by changes to the impact areas personal mobility, traffic safety and efficiency and the environment. These changes are evaluated for different automated driving (AD) modes: Automated Valet parking, Urban Driving, Highway pilot and Platooning.

The report studies quality of life from a societal rather than an individual perspective focussing on impacts coming from changes in the transport system created or augmented with IoT and automation. The objective of the AUTOPILOT project being to explore how IoT can accelerate, enhance and enable automated driving, the quality of life assessment aims to identify and describe the most relevant impact mechanisms, through which IoT could enhance automated driving. The focus is on qualitative assessment, including initial estimates on direction and level (small/large) of changes. The results of the assessment per impact area (personal mobility, safety, efficiency, environment) are presented for each AD mode. The resulting expected implications on societal quality of life (health, well-being and equity) are described for all modes collectively.

This work uses a methodology based on the impact assessment framework developed by the Trilateral ART WG (the Trilateral Working Group on Automation in Road Transportation between the US, EU and Japan). The ART-WG impact assessment subgroup has looked at potential impact mechanisms, for which Innamaa (2019) has elaborated an updated version used for quality of life assessment in AUTOPILOT. This approach allows for all the available, rather fragmentary, information on potential impacts of automated driving and IoT to be utilised systematically, without losing sight of the big picture – that is the complex system formed by several interrelated impact mechanisms, where changes to one mechanism can have both negative and positive impacts on others.

Potential benefits of IoT and automated driving evaluated in AUTOPILOT include smoother driving and more reliable trips. These are expected due to better anticipation of and reaction to other road users as well as events and road conditions ahead. Shorter headways between vehicles and better anticipation offer potential improvements to traffic safety, efficiency and the environment and travel comfort and convenience are expected to increase.

The assessment showed that AUTOPILOT AD modes have potential to improve quality of life, but benefits are not self-evident. Due to the complexity of the transport system as well as uncertainties in the development and deployment of automated driving and connectivity with IoT, impacts are challenging to estimate. Personal mobility and travel patterns have a large influence on the size and direction of impacts. Thus, he impacts on quality of life are to a large extent dependent on how the AD services are implemented, deployed and regulated. It is important to note that the results of this work are theoretical. It is assumed that connectivity between vehicles and infrastructure is available, widely in use and working as intended. Therefore, the results disregard potential challenges in uptake and deployment of the services.

1 Introduction and background

1.1 Purpose and structure of the document

This document presents the methodology and results of the Quality of Life evaluation in the AUTOPILOT project. Quality of life impacts in this context are defined as the potential impacts on well-being, health and equity, reflected by changes to traffic safety, traffic efficiency and the environment, and personal mobility.

In Chapter 1 background is provided on the AUTOPILOT project in general and the assessed functions in particular. Key concepts – IoT, automated driving, and quality of life – are introduced and their use within this report explained. The objectives and scope of the study are presented in Chapter 2. Chapter 3 describes the methodology of the study, and Chapter 4 presents the results. Implications for societal quality of life are presented in Chapter 5. Finally, Chapter 6 provides a discussion of the results and forms conclusions.

In should be noted that, in contrast to the other evaluation areas in AUTOPILOT, as for instance technical or business impact evaluation, the Quality of Life assessment has a wider focus. It is not directly assessing the impacts of the pilot tests, but rather tries to identify the potential impact pathways and relationships, which lead to changes in societal quality of life. The work assumes that the technology is working and in wider use.

1.2 AUTOPILOT project and pilots

The AUTOPILOT (Automated driving progressed by Internet of Things, 2017–2019) project under the European Horizon 2020 programme has developed and tested IoT based AD modes and services with automated driving enhanced, accelerated and/or enabled by IoT: automated valet parking (AVP), urban driving, highway pilot, platooning and ride sharing. They have been piloted and evaluated at five test sites around Europe located in Vigo (Spain), Tampere (Finland), Versailles (France), Livorno (Italy) and Brainport (the Netherlands) (Table 1). In addition, an associated pilot site was located in Daejeon, Korea.

Scholliers et al. (2018), Mathews et al. 2019 and Schreiner et al. 2019 present detailed descriptions of all the piloted AD modes as well as expected benefits of IoT. To assess user acceptance and potential impacts of the services on personal mobility, user tests were conducted at the pilot sites. Due to limitations set by legislation and the prototype nature of the technologies, the vehicles were mostly driven by authorised drivers.

In order to harmonise the piloting activities across the different sites and ensure coherent evaluation, a pilot protocol was developed together with the tasks focusing on user acceptance and business impacts. The general purpose of this protocol was to provide general guidelines for the pilot sites on how to conduct the user activities. The protocol also included draft versions of user surveys, consent forms, project presentations, information sheets for participants etc. that the pilot site customised to the local conditions and tested use case. Most of the pilot sites used company employees or safety drivers as users, naïve users were recruited only in Tampere. More information on the user tests and user acceptance can be found in Ertl et al. (2019).

Table 1 – AUTOPILOT Use Cases piloted and evaluation at different Pilot sites

AD modes	Tampere	Versailles	Livorno	Brainport	Vigo	Daejeon
Automated valet parking	X			X	X	
Highway Pilot			X	X		
Platooning		X		X		
Urban Driving	X	X	X	X	X	X

1.3 Terminology and key concepts

1.3.1 Internet of Things

The term "Internet of Things" (IoT) reflects the rising level of connectivity between different objects in the world through the use of the Internet. Not only phones and computers are connected but to an increasing extent so are objects such as household devices and vehicles. This connectivity enables information exchange between these objects and consequently enhanced services and also completely new types of services.

The IEEE Standards Association (Minerva et al. 2015) broadly defines IoT as a system consisting of networks of sensors, actuators, and smart objects whose purpose is to interconnect "all" things, including every day and industrial objects, in such a way as to make them intelligent, programmable, and more capable of interacting with humans and each other.

The capabilities of smart connected products can be categorized into four groups: monitoring, control, optimisation and autonomy. Each of the groups builds on the preceding one (Porter 2014). Monitoring capabilities include sensors and external data sources enabled monitoring of the products condition, external environment and product's operation and usage. Monitoring also enables alert and notifications of changes in operation and usage of product. Control capabilities include embedded software, which enables control of products functions and personalisation of the use experience. Together monitoring and control capabilities enable algorithms that optimize product operation and use in order to enhance product performance and predictive diagnostics, service and repair. Combining previous ones allows self-coordination of operation with other products and systems, and self-diagnosis and services, which are considered as autonomy capabilities.

1.3.2 Connected and automated driving

In the context of Quality of Life evaluation in AUTOPILOT, the use of IoT in automated driving is referred to as connected automated driving (CAD); as opposed to autonomous driving, where the vehicle relies only on its own sensors to perform all driving related tasks. Connected automated driving enables information exchange between vehicles (V2V) and/or vehicles and the infrastructure (V2I). The term "connected and automated vehicle" (CAV) refers specifically to automated vehicles that are connected to each other (vehicle-to-vehicle, V2V) or to their environment (vehicle-to-infrastructure, V2I) (e.g. Cavoli et al. 2017). V2V communications provide detailed information about vehicles' movement and drivers' operational decisions (e.g. speed, acceleration, and location) while

V2I communications can provide detailed information about road conditions, weather condition along other traffic management control decisions (Talebpour and Mahmassani 2016).

Automation in road transport is defined as systems that are able to perform “part or all of the Dynamic Driving Task” (all of the real-time operational and tactical functions required to operate a vehicle in on-road traffic) “on a sustained basis” (Alonso Raposo et al. 2019, SAE International, 2016). Different levels of automation are distinguished, depending on the degree of responsibility given to the system or the driver/user. The AUTOPILOT project deals with high level automation in restricted ODDs (operational design domain).

The term “connectivity” is used to refer to use of technologies, which enable road vehicles to communicate with each other and/or with the roadside infrastructure, such as traffic signals (Alonso Raposo et al. 2019). Connectivity enables the concept of C-ITS (cooperative intelligent transport systems) and is linked with vehicle automation. According to the European Commission (2016), connectivity, cooperation and automation are complementary technologies that reinforce each other and can over time merge completely.

Combined together with two other major ongoing trends in transportation (decarbonisation and sharing, Alonso Raposo et al. 2019), automation and connectivity are expected to lead to radical transformation of the road transport system, as interplay and integration between the four areas has a reinforcing effect (Alonso Raposo et al. 2019). While decarbonisation is not explicitly addressed in AUTOPILOT, vehicle sharing is a key part in some of the AD modes piloted.

Different scenarios of introducing automated driving on the market can be defined. Fraedrich et al. (2015) discuss three general transition pathways to fully automated driving – evolutionary further development of driver assistance mainly in private vehicles, revolution of personal mobility due to raising market share of mobility and vehicles on demand, and a transformation of personal mobility combining the advantages of personal mobility and public transport. The use of IoT might progress automated driving in all three scenarios. The use cases tested in AUTOPILOT refer to the first two scenarios – first, automation in future private vehicles, and second, enabling flexible car –and ridesharing concepts using IoT and automation. Hence, considering impact of automation in personal mobility in the quality of life evaluation of the project, potential and challenges related to the implementation of the tested services in the context of private or shared fleet will be addressed.

The focus of AUTOPILOT is automated driving with IoT-enabled connectivity between vehicles or between vehicles and the infrastructure, on passenger cars. The AD modes addressed represent a high level of automation, but are limited in time and space. Technical details related to the deployment and implementation of the AD modes are not addressed in this work. For quality of life assessment, it is assumed that the AD modes are widely in use and that both the systems and the connectivity via IoT work as intended.

1.3.3 Quality of life

In this assessment, quality of life is studied from a societal rather than an individual perspective. However, even if the perspective is societal it is limited - the focus is on impacts coming from changes in the transport system with IoT and automation. In this context, societal quality of life is considered to be formed by the impact areas Health (morbidity and mortality), Individual quality of life (well-being) and Equity. These implications of AD modes on quality of life are formed by changes to the impact areas of personal mobility, traffic safety, traffic efficiency and the environment.

2 Objectives and scope

AVs are a complex and multi-faceted issue affecting population health and wellbeing (Dean et al. 2019). Despite extensive ongoing work around AV and large attention from researchers and policy makers among others, there is a lack of knowledge on the societal impacts of AV (Dean et al. 2019, Milakis et al. 2017). This study aims to contribute to this knowledge gap by examining the most important impact mechanisms leading to societal impacts.

Research questions define the objectives for quality of life assessment. Research questions for evaluation were formulated at the beginning of the project (Netten et al. 2018). The objective of the AUTOPILOT project is to explore how IoT can accelerate, enhance and enable automated driving. Due to many uncertainties around the topic of automated driving and IoT, the quality of life impact assessment takes an explorative approach: Rather than trying to produce estimations of quantitative impacts, which would rely on many uncertainties and assumptions, the aim is to identify and describe the most relevant impact mechanisms through which IoT could enhance automated driving and provide some initial estimates on direction and level (small/large) of changes.

The main objectives of the quality of life assessment are to:

- Explore how IoT in automated driving meets personal mobility needs
- Explore the improvements in transport system efficiency with various penetration rates of IoT devices and automated driving vehicles.
- Explore the contribution of AD in IoT to traffic safety improvements
- Explore the contribution of AD and IoT to citizens' health, well-being and equity

The mechanisms how IoT could accelerate, enhance or enable the development, functionalities, performance and benefits of automated driving functions and services are studied.

The impact assessment process starts by the definition of the function descriptions for each assessed AD mode. These descriptions are required for the identification of expected user reactions and impacts and they focus on a user point of view. This means that the implemented technological details are not relevant as such, but only the functionalities and features that the users see and experience. In addition, any restrictions related to the performance of the function should be known. The implementations of use cases differ somewhat between different pilot sites. Therefore, to be able to combine results and get a broader perspective, the individual descriptions from different pilot sites are combined into one "general function", according to their basic functionality or purpose. These are described and explained more in detail in chapter 3.4.

Both a top-down approach starting from the impact areas encompassing quality of life as well as a bottom-up approach, starting from the piloted AD modes, were taken in the assessment. The research questions formulated for QoL impacts in AUTOPILOT have a more explorative character.

Compared to ADAS, AD impacts are also estimated to be more far-reaching. Therefore it is important to distinguish between the top-down and bottom-up –approaches, trying on the one hand to be as precise and detailed as possible, but on the other hand not losing sight of the wider impacts that automation and IoT may bring.

The purpose of the assessment was to cover both direct and indirect impacts, keeping in mind that the societal and individual goals may be conflicting.

3 Methodology

3.1 Impact assessment framework

The methodology of this work is based to a large part on the impact assessment framework that was formed by the Trilateral ART WG (the Trilateral Working Group on Automation in Road Transportation). The ART WG was established in 2012 as a cooperation between the European Union, USA and Japan, and it aims to address the complex impacts of AV. A sub-group for impact assessment was established in 2015 with the aim to harmonise field tests approaches to achieve complementary evaluation worldwide.

This subgroup has looked at potential impact mechanisms, through which AD is expected to impact our lives, with the aim to cover both direct and indirect impacts. These impact mechanisms have been visualised in impact path frameworks for the areas traffic safety, network efficiency, emissions and use of materials, personal mobility and quality of life, equity and health. (Note that quality of life is considered as a narrower concept in the work of the ART WG. As stated earlier, the AUTOPILOT study takes a broader view on quality of life.) The impact mechanism framework has been further elaborated by Innamaa (2019), and this updated version forms the basis for quality of life evaluation in AUTOPILOT as described in this report. This framework was chosen because it provides to the knowledge of the authors the most comprehensive picture of potential impacts of automated driving on the transport system and society, showing also the potential impact mechanisms and pathways leading to these impacts.

The framework was applied to the five AD modes tested in the AUTOPILOT project. This approach, using the assessment framework as a basis, ensured that the potential impacts were considered systematically, including different potential impact mechanisms and both direct and indirect impacts.

The impact assessment framework shown in Figure 1 consists of four main blocks:

Block 1: Forming the *Use of AD*: *Acceptance* and *Transport system*
Block 2: Forming *Mileage per mode*: *Vehicle operations, AD user, Quality of travel, Transport offering, Driving quality*, and *Behaviour and skills*
Block 3: Forming the *impacts* on the transport system level: *Safety, Efficiency, Infrastructure, Environment, Travel behaviour* and *Land use*
Block 4: Based on all previous areas, forming the impacts on *societal Quality of Life*: *Public health, (Individual) quality of life*, and *Equity*

The *Block 2* ***Mileage per mode*** is in the main focus of this study, as it determines the scope and size of impacts on personal mobility, traffic safety and efficiency and the environment, and therefore the implications of AD and IoT on societal quality of life.
Block 1 ***Use of AD*** is not explicitly considered, as this relates to the uptake, acceptance and availability of the AD modes, which in this analysis are considered already given. *Block 3* ***Impacts*** regards the expected impacts of the AD modes on the transport system level. These are formed by changes to *Block 2*. Finally, implications on ***societal Quality of life*** are considered in *Block 4*.

A detailed description of the mechanisms of the framework can be found in Annex 1.

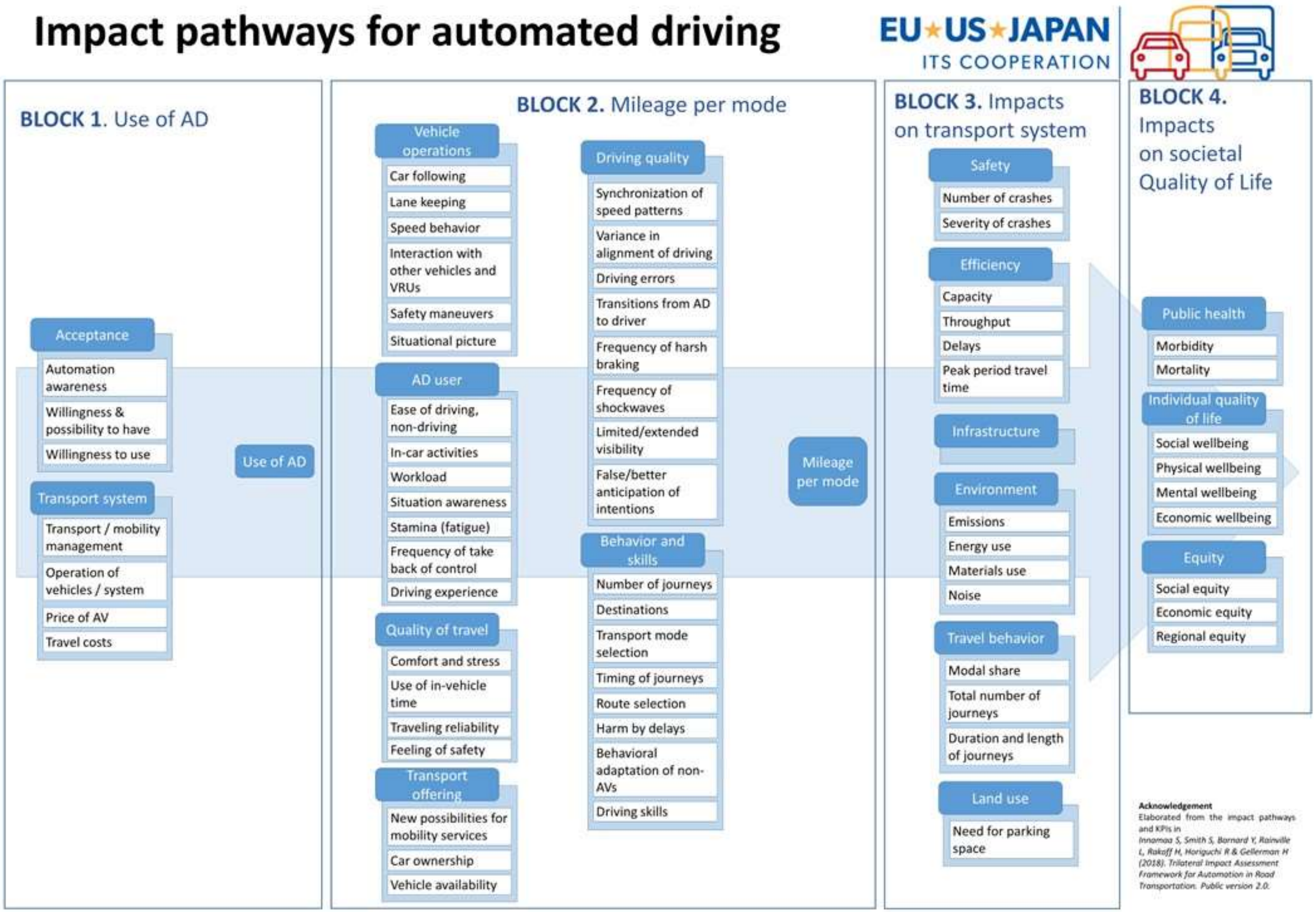


Figure 1 – Impact pathways for automated driving (Innamaa et al. 2018, Innamaa 2019). Modified.

3.2 Main steps of methodology

The methodology for systematic assessment of potential impacts of CAD, based on the piloted AD modes in AUTOPILOT, included the following six steps:

Step 1: Mapping of mechanisms for the impact areas personal mobility, traffic safety and efficiency & environment to the impact pathways figure. The mapping was done based on previous work, where available:

- Personal mobility: TeleFOT mobility model (Innamaa et al. 2013), expert workshop
- Traffic safety: Impact mechanisms (Kulmala 2010, Innamaa et al. 2018), expert workshop
- Efficiency & Environment: literature, expert workshop

Step 2: Mapping of mechanisms where IoT is expected to have an effect, per AD mode, when compared to the baseline, automated driving without connectivity (IoT).

Step 3: Merging of Step 1 and Step 2 results to find the relevant impact mechanisms of IoT for each AD mode and impact area

Step 4: Collecting evidence on the potential impacts of CAD on the considered impact areas through the available data sources, including pilot tests, other evaluation tasks of the project, stakeholders, experts and literature.

Step 5: Integration of the collected information from different available sources (step 4) with the results from step 3 to identify the most relevant impact mechanisms and potential impact directions.

Step 6: Defining general implications of CAD on societal quality of life based on the results per AD mode.

Most of the work in *Steps 1–6* was carried out in expert workshops. In *Step 4*, all available kinds of information from the pilot tests, stakeholder interviews as well as relevant literature was collected for each of the mechanisms described in *Block 2* of Figure 1.

For each of the boxes in Figure 1, the different kinds of information that was available were determined. The main information source was literature, such as reviews and expert assessment. The main studies considered were carried out by the JRC (Alonso Raposo et al. 2019) and within the CEDR funded MANTRA project (Penttinen et al. 2019), and the EU funded CARTRE project (Rämä et al. 2018). In addition, data from the AUTOPILOT online questionnaire about user acceptance, user surveys within the pilot tests as well as focus groups and stakeholder and expert interviews and workshops was used. Further, system dynamic modelling of impact pathways provided a way to extend the assessment framework by modelling causal loops for certain scenarios. The strong link to ongoing work by expert groups was considered helpful because of the complexity and uncertainties in the field of automated driving.

In transport operations, three main policy objectives are increasing efficiency, lowering environmental impact and improving traffic safety (Vreeswijk and Blokpoel 2013). These objectives can be understood as minimising travel times, fuel consumption, CO_2 emissions and accidents. There are however conflicts between these areas, and no ideal combination of measures results in an optimal situation for all three objectives (Wismans 2012). Efficiency and environmental impacts tend to be aligned with each other, as are environmental and safety impacts, but some impacts may also be opposed to each other, efficiency and traffic safety impacts in particular. As data on emissions is not easily obtained, efficiency indicators (such as travel time) can be used as surrogate indicators.

It is recognised that there are overlaps and interactions between the different boxes of the framework. However, for reasons of simplicity and to avoid over-complication each box was considered one at a time and, for the impact analysis on safety, efficiency, environment and personal mobility, pairwise.

Several assumptions were made in the assessment. The IoT is assumed to be in place and working, and IoT based AUTOPILOT services are assumed to be used in AVs. The baseline used in the assessment is autonomous (non-connected) driving (SAE level 4) or, for the automated valet parking service, automated parking with user supervision, where the user needs to assign a free parking space and supervise the parking process.

3.3 Considered impact areas

3.3.1 Personal mobility

The term *personal mobility* describes the travel behaviour (and the reasons behind it) of individuals, including choice of destination and travel mode, to analyse the travel demand in a population on an aggregated level. Understanding, modelling and forecasting travel demand is an important research area supporting transportation planning and the development of policy measures in transportation (Ortúzar and Willumsen, 2011). Theoretical approaches and empirical work aiming to understand personal mobility and mobility-related needs usually look into determinants of mode choices. These can be divided into three groups: individual characteristics (e.g., age, gender, car availability, attitudes), journey characteristics (e.g. trip purpose) and alternative-specific characteristics which can be divided into quantitative factors, such as travel time and cost, and qualitative characteristics, such as comfort, convenience and demand of the driving task (Ortúzar and Willumsen, 2011).

Another way to structure mobility impact assessment is proposed by the mobility model (Innamaa et al. 2013, see Figure 2), which is a theoretical tool built to identify and account for the relevant factors related to mobility. The model proposes three main areas for personal mobility: amount of travel, travel patterns and journey quality, which are further divided into more specific topics. The model specifies personal variables that affect personal mobility choices, travel decision-making variables, travel characteristics followed by decisions and their relationships. The tool also helps in determining, which specific aspects need to be measured or evaluated in order to analyse mobility impacts, and can help with data analysis. The mobility model was originally developed for the TeleFOT project (Innamaa et al. 2013) and used e.g. in the projects DriveC2X (Malone et al. 2014) and TEAM (Aittoniemi et al. 2016). The main parts of the mobility model are highlighted in the framework picture in Figure 3.

Potential impacts on personal mobility were derived from user tests, focus groups, literature and expert interviews.

In the interpretation of impacts from a personal mobility point of view, the basic principles of Innamaa et al. (2013) were applied:

- Mobility improves as the number of journeys increases.
- Mobility improves as the length of journeys measured in distance or as duration decreases (personal efficiency improves)
- Change in used modes either improves or reduces mobility based on user preference (whether they favour a car, public transport, etc.).
- Route choice either improves or deteriorates mobility based on user preferences (whether they favour a motorway, rural roads, etc.). It can be assumed that if the user is (voluntarily) willing to change route, he/she considers the new route better.
- Mobility improves as management of time budget for travelling improves, e.g. as departure time of commuting is shifted later.
- Mobility improves as travelling in adverse conditions such as darkness increases.
- Mobility improves as quality improves in terms of less stress and uncertainty or a better feeling of safety or comfort

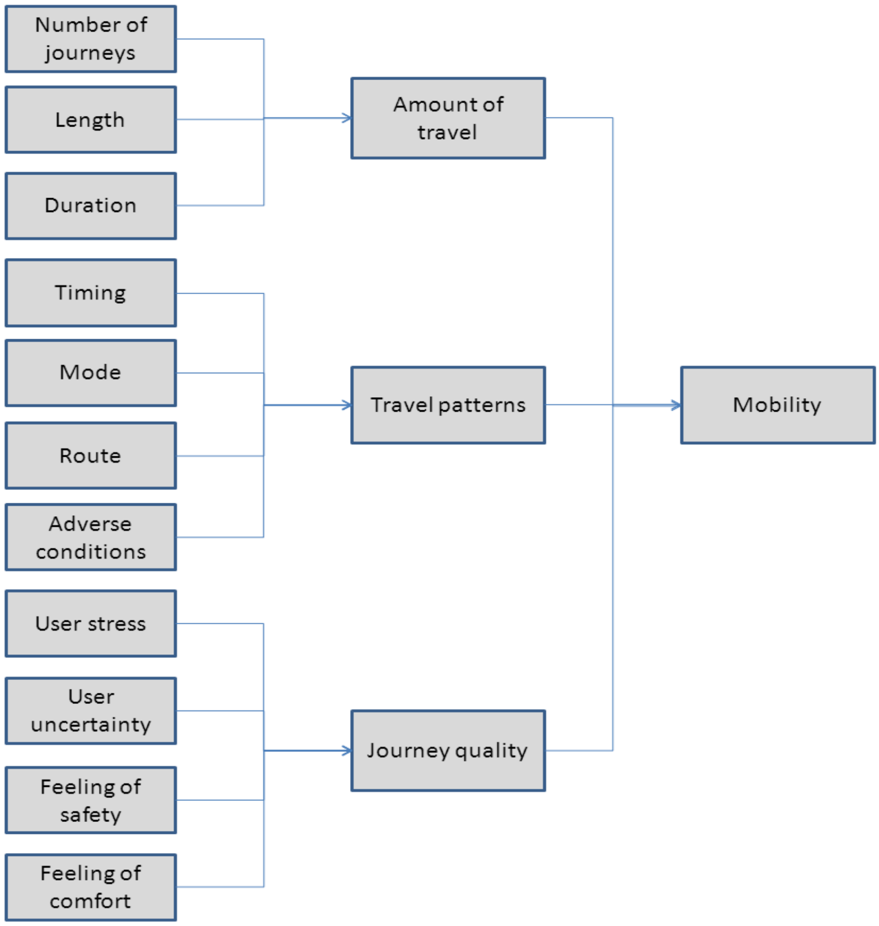


Figure 2 – Mobility model (Innamaa et al. 2013)

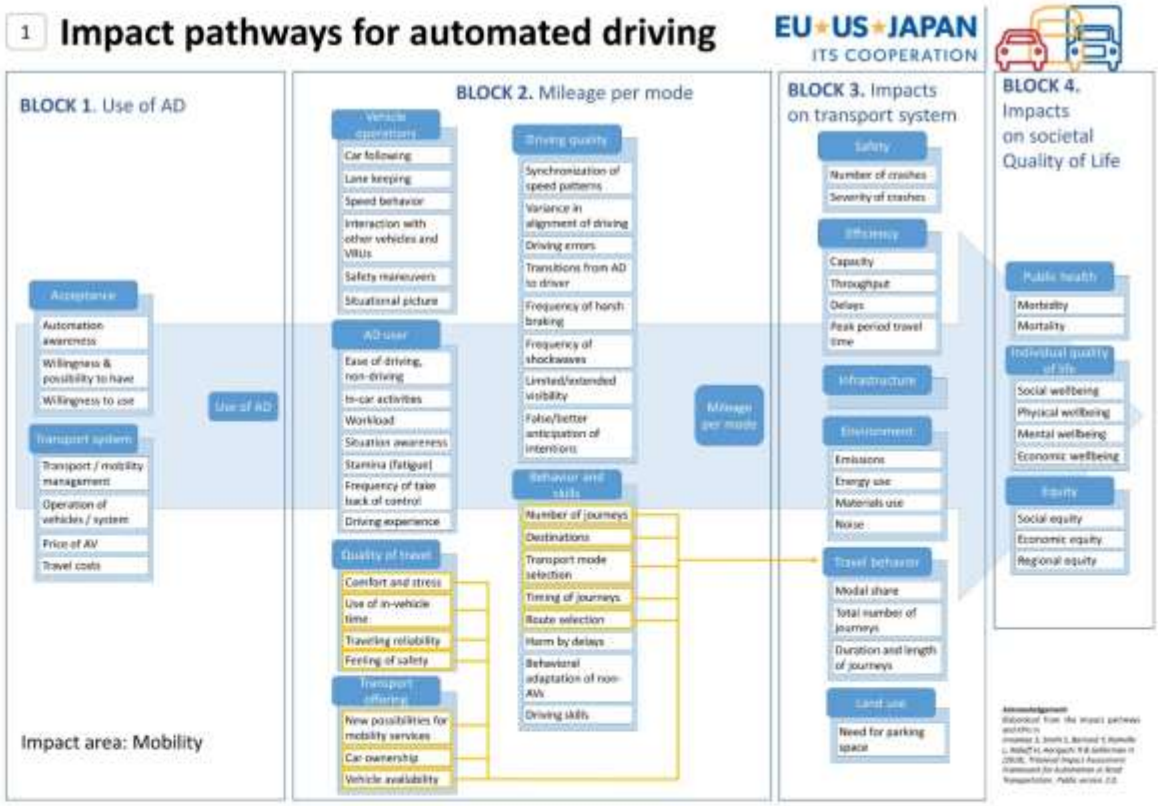


Figure 3 – Impact paths of automated driving for the impact area Mobility.

3.3.2 Traffic safety

Traffic safety can be described in terms of the number of accidents, which is related to three main factors: exposure, risk and consequence (Nilsson 2004). Exposure represents the amount of activity where an accident can occur, risk is the expected number of accidents per unit of exposure and consequence is the severity of the accident. Traffic safety can, therefore, be influenced by a change in any of the three dimensions. Exposure is related to the amount of travel (number and duration of trips), while risk represents the difference in accident risk in different road environments or with different travel modes.

Innamaa et al. (2018) developed a high-level impact assessment framework for harmonising evaluation of automated vehicle pilots. This evaluation framework is based on the nine impact mechanisms proposed by Kulmala (2010) for systematic ex-ante evaluation of the safety impacts of intelligent transport systems (ITS; see Table 2). Both the engineering and behavioural adaptation effects are covered, relating to all three dimensions of traffic safety (exposure, risk and consequence). Nine impact mechanisms, which emphasise the direct and indirect modification of both user and non-user behaviour, were proposed by Kulmala and adapted for automated driving by Innamaa et al. (2018). It is important to be noted that the framework includes also changes in exposure i.e. the mobility of road users (Innamaa et al. 2018).

The impact mechanisms for traffic safety are shown in the assessment framework in Figure 4.

Table 2 – Impact mechanisms for systematic ex-ante evaluation of ITS safety impacts.

Safety dimension	Impact mechanism
Risk	Direct modification of the driving task, drive behaviour or travel experience
	Direct influence by physical and/or digital infrastructure
	Indirect modification of AV user behaviour
	Indirect modification of non-user behaviour
	Modification of interaction between AVs and other road-users
Exposure	Modification of exposure /amount of travel
	Modification of mode choice
	Modification of route choice
Consequence	Modification of consequences due to different vehicle design

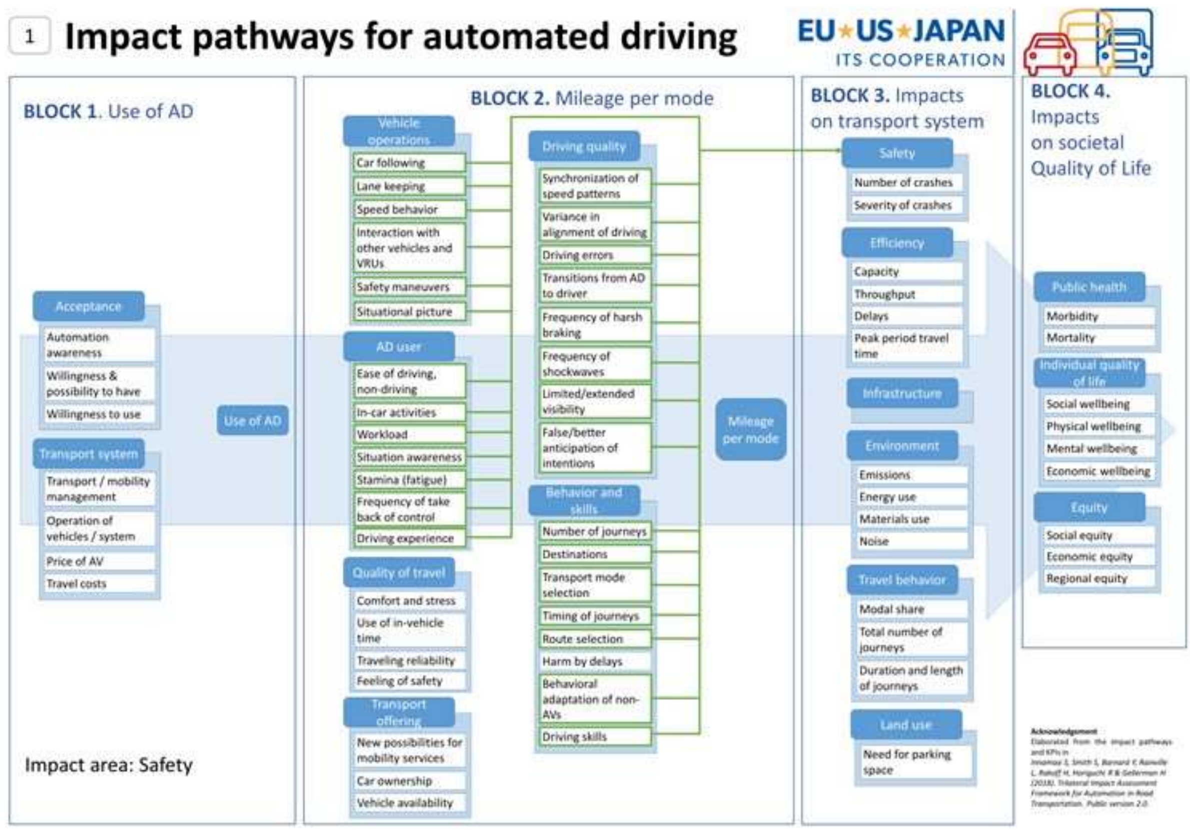


Figure 4 – Impact paths of automated driving for the impact area Safety.

3.3.3 Traffic efficiency and environment

Traffic efficiency describes traffic performance on a network. Efficiency can be measured by different indicators, such as capacity of a lane, link or intersection, throughput or traffic volume, travel time, delay time and travel time reliability (Innamaa et al. 2018). Traffic efficiency is directly affected by the driving style, e.g. headways kept between vehicles, but also indirectly through mobility behaviour (such as amount of travel, mode choice, routes and destination choices) and traffic safety, due to a potential reduction of delays caused by incidents. The impact paths for the impact area efficiency and environment are highlighted in Figure 5.

Traffic congestion is an increasing problem in cities around the world, causing harmful effects on the citizens' quality of life, for example in time losses and pollution (reference). Connected automated driving has potential for harmonising traffic flow and optimising the transport system (reference), for example by allowing for better anticipation of events and a smoother driving style. For example, vehicle automation can help keep headways and other driving behaviour more constant and reduce fluctuations caused by human driving behaviour, thus reducing the amount of disturbances and increasing road capacity as well as lowering emissions.

So far, the research on impacts of automated driving has been mostly limited to simulation studies and controlled field tests, with mixed results. The network efficiency impacts are mainly dependent on the level of automation and cooperation and the penetration rates (Milakis et al. 2017). Many of the studies concern motorways, and the potential benefits for urban centres are even less clear, as they are characterised by short distances between intersections and the presence of many different types of road users (POLIS 2018).

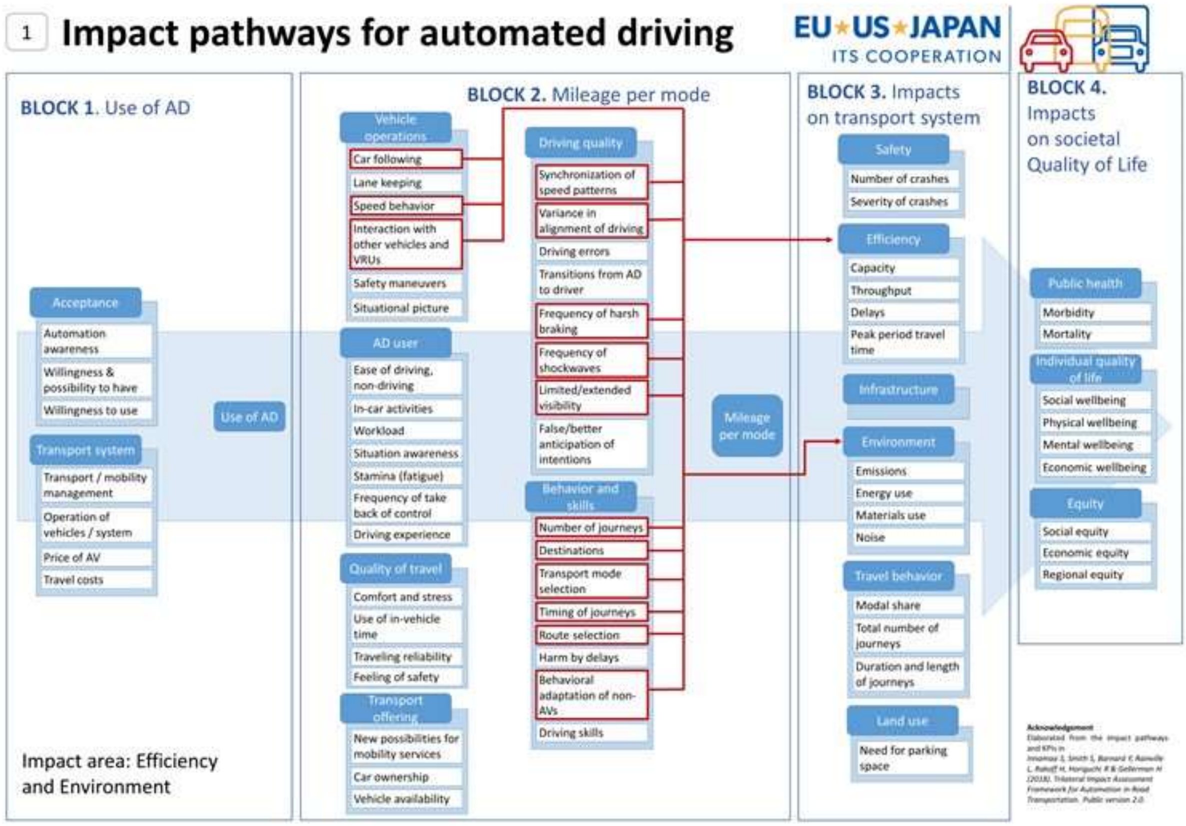


Figure 5 – Impact paths of automated driving for the impact area Efficiency and Environment.

3.3.4 Individual quality of life and well-being

Individual quality of life is a broad ranging concept affected in a complex way by the person's physical health, psychological state, level of independence, social relationships, and personal beliefs combined with their relationship to salient features of their environment. Further, individual quality of life can be seen as an overarching concept that covers all aspects of a person's life, which includes, amongst others, physical well-being, psychological well-being, financial well-being and social well-being. Physical well-being includes e.g. the fitness, energy and occupational performance indicators, whereas psychological well-being include mental health, self-perspection and mood indicators. Social well-being consists of family relationships, friendships, and level of community involment. And finally, economical well-being covers the financial resources and access to job opportunities and services. The World Health Organization (WHO 1997) states that quality of life is individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns.

The task of driving is a complicated activity, one that is undergoing a transformation as a result of the rise of IoT and Automated Vehicles. To this end, it is essential to understand, measure and keep track of drivers' well-being and the factors that affect it throughout the full lifecycle of the upcoming transformation.

Starting with the definition of well-being, it can be perceived as "how people feel and how they function, both on a personal and a social level, and how they evaluate their lives as a whole". To break this down, how people feel refers to emotions such as happiness or anxiety.

The World Health Organization's definition of health clearly underscores the importance of well-being: "*Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*." Well-being is a broad concept that entails multiple dimensions, which can essentially be divided into two large domains: objective and subjective well-being. As a result, various scales and indices have been developed to measure both domains.

Well-being is generally considered a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity. The topic has been extensively researched in several areas of psychology, ranging from hedonic psychology field (Kahneman et al. 1999), economics of happiness (Bruni and Porta 2007) and positive psychology (Seligman 2002). Subjective and measurable well-being indicators have been widely used, as being very relevant to research and, consequently, there are numerous such surveys conducted across the world (e.g. World Values Survey 2009).

A number of factors affect the well-being of drivers, such as stress, fatigue and lone working. In terms of stress, it affects drivers' ability to make decisions and react quickly or appropriately as well as affecting their overall standard of driving. Fatigue and sleep deprivation is also measured to be the cause of around 20% of incidents on the UK's roads while lone working of professional drivers can have an impact on their mental health and well-being. The effects of stress, regardless of the cause, can leave drivers prone to make irrational decisions and suffer road rage.

Lee and Sener (2016) have indentified four classes of QoL definitions: (1) objective, (2) subjective, (3) combination of objective and subjective, and (4) domain-spefic. They emphasise that quality of life is an inherently individualised concept. Thus, objective measures fail to reflect individuals' perceptions, but serve the purpose of understanding societal impacts. The subjective approach to quality of life attempts to encompass life satisfaction and feelings of positive and negative affects to provide more individual measures. However, attempts to define QoL solely through subjective indicators have their weakness too, as subjective indicators fail to capture one's life state as a whole. For example, Felce and Perry (1995) have stated that human welfare is not entirely reliant on personal satisfaction because it can not alone represent the individuals' circumstances. Nowadays, the state of art is that quality of life should be interpreted as combination of these two – objective and subjective nature of the QoL. Quality of life can also be approached under different domains. Domain-specific QoL definitions are not as universal as the previous, and on this account they can be more useful in their respective fields by offering more precice outline in the ways QoL is interpreted (Atkinson 2013).

There are some studies on causal relationships between transport and quality of life to be found, but there is no overarching definition and the approaches vary strongly. One way to approach transport related quality of life is to divide it into access and availability, environment, sustainable transport, personal safety and transport costs, which together represent the *journey quality* (Carse 2011).

Another way to approach individual quality of life under the domain of transport is Lee and Sener's (2016) model for transportation and quality of life, which concludes built environment, mobility and accessibility, and vehicle traffic as the main determinants for transport related quality of life. The model presents both subjective and objective determinants of *individuals' perceived quality of life,* related to different areas of well-being, under the domain of transportation. Figure 6 presents the linkages between different categories of well-being according to Lee and Sener (2016).

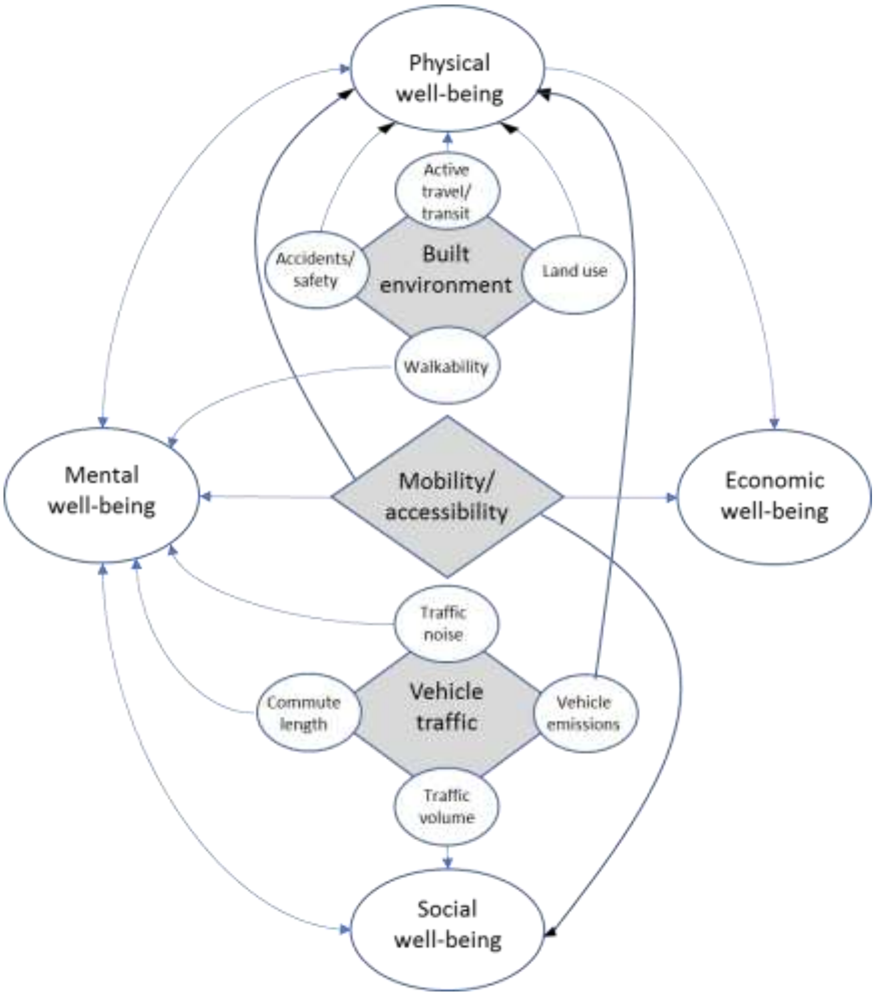


Figure 6 – Transportation and quality of life. Adapted from Lee and Sener 2016.

Personal mobility in general is highly correlated with well-being and contributes to individual Quality of Life. However, there is less research specific to the area of transport, and well-being is often defined with reference to the study objectives and research hypotheses in relation to a utility or behavioural choice model. The relationship does not seem to be linear as personal transportation can have positive (e.g. comfort, increase social contacts, transfer to work) and negative effects (e.g. stress, tiredness) on well-being, as well as pose risks to well-being (e.g. accidents, air pollution, decreased use of active travel modes).

On one hand, wellbeing is expected to improve with AV because the value of time spent in transport will change. Passengers will be able to engage in their preferred activities, ones they cannot get involved right now (e.g. work, sleep, watch a movie). However, in a survey performed by Cyganski and colleagues (2015) in Germany, respondents stated that the activities they will be involved in during automated driving will be mostly window gazing, listening to music and talking on the phone;

which are actually secondary activities that they already engage whilst driving. Hence, results are not so straightforward because the automated driving paradigm shift offers a disruption to a major daily activity, such as driving. The positive effects, hence, are not sot immediate and easy to identify, as they were theoretically expected to be. However, the effect on user groups that had not access to driving until now (e.g. older drivers, individuals with disability) might be a more direct measure of increase in wellbeing for these groups.

On the other hand, research warns that increase in VKT because of the availability of AVs could have detrimental effects on public health because they could lead to physical inactivity (Clark et al. 2016; Fagnant et al. 2015) and more people could choose AVs over public transport (Thomopoulos and Givoni, 2015). A solution to this problem is not easy but targeting shared mobility options over private ones might be a long-term mitigation strategy (Diels et al. 2017).

3.3.5 Health

Transportation and health are closely interlinked, and this link is recognised as an important issue in policy making, for example through Vision Zero, UN Sustainable development goals, and walkable communities (Dean et al. 2019). However, despite much research on AV being done, there is little literature examining the potential broader health impacts. Health issues in connection with AV have been focused on improving road safety, while more general social impacts have included improving independent mobility for populations unable to drive, such as elders. These issues are important, but do not include the broad range of potential positive and negative impacts that AV can have on health (Dean et al. 2019). Further, due to lack of research, most literature on societal impacts of AV is speculative.

The role of AVs in public health is not clear and understood and findings mostly result from surveys administered to general public focussing on respondents' opinions and imagination (Kyriakidis et al. 2015). There is limited research presenting results from actual use because the effect on wellbeing and users' health requires a long-term use and longitudinal assessment of relevant indicators (e.g. stress, comfort, happiness, pleasure). Literature suggests that AV have a clear and direct role on health, especially related to reductions of road-related injuries and fatalities (Dean et al. 2019). Beyond this direct impact through road safety, there is a lack of consensus on the AV impacts on human health. The US DOT has recognised five pathways for the links between transport and health (Dean et al. 2019): active transportation, road safety, air quality, connectivity (accessibility), and equity.

Important measures when discussing the health impacts of transportation are mortality and morbidity (Mäkinen 2019). Mortality is measures as years of life lost and potential years of life lost. They are easier to quantify than morbidity, which measures years lived with disability and disability-adjusted life years. The mortality measure gives more weight to deaths that occur among younger people as they were expected to have more life years ahead of them. Morbidity aims to quantify the burden of living with a disease or disability. Quality of life can be measured as quality-adjusted life years and healthy life expectancy. Literature shows positive associations between morbidity outcomes, premature mortality rates, stress and traffic congestion (Milakis et al. 2017).

The choice between active and passive travel modes has great influence on people's physical activity levels (Sallis et al. 2016). Studies indicate that provision of specific infrastructure for pedestrians and cyclists is associated with higher levels of use of these modes, and therefore with health benefits (Milakis et al. 2017). On the other hand, increase in vehicle use through AVs can have negative impacts, if use of active transport modes and therefore physical activity levels decrease.

Active travel modes help in reaching recommendations for physical activity goals (Schalkwyk and

Mindell 2018). While not an active mode itself, public transport use typically involves walking or cycling to and from the nearest stations. Transport systems where use of private vehicles and other motorised vehicles is prioritised, lead to increased exposure to related harms such as air pollution, noise pollution, accidents, community severance, poor mental health and reduced social interaction (Schalkwyk and Mindell 2018). The convenience of private car use does not encourage active travel modes, and transport policies, which centre on private vehicle use, limit the opportunities for and likelihood of physical activity and associated health benefits.

The uncertainty and range of possible outcomes is important to consider when discussing the potential impacts of AV on health (Dean et al. 2019). Factors such as ownership model, fuel source and regulations by public and private entities play a role, and the impacts and their degree depend on which of these scenarios are realised. A lot of the uncertainty is due to uncertainty of how AVs will be implemented into the existing transport system. The most important unclear variables are ownership models, fuel source, government regulations and user experiences (Dean et al. 2019). There is potential both to encourage active transportation in combination with AVs and to discourage it completely.

3.3.6 Equity and accessibility

Transportation can have significant social impacts (Milakis et al. 2017). Accessibility to transport options determines to a degree the options people have available to pursue employment, social interactions and leisure activities as well as access to necessary services such as health services. Often these factors are interlinked, and e.g. people from lower income groups live in areas with lower accessibility, therefore creating a vicious circle.

Findings from literature suggest that overall the social, behavioural and societal aspects of AV are under-researched (Cavoli et al. 2017). It is known that AV introduction can have positive and negative implications for accessibility (Milakis et al. 2017). However, those implications largely depend on the ways AV are deployed and implemented. If vehicles will continue to be mostly privately owned as it is today, the first AV are likely to be expensive, which limits benefits from AV, such as increased comfort and safety, to wealthier citizens. If increased AV use leads to less use of public transport, the level of service and thus accessibility for people in lower socio-economic groups may decrease further. On the other hand, if AV are mostly in shared use and serve as a way to reach stations for high capacity public transport, also the lower income groups may benefit. Impacts can be far-reaching: conversion of redundant road and parking space to better VRU infrastructure and more housing can increase housing affordability.

3.4 General AD modes for QoL assessment

3.4.1 Purpose and scope of general AD modes

In an expert workshop the function descriptions were developed and needs of potential users were mapped to the specific problems that the introduced AD modes could address.

In contrast to other evaluation task in the project, the quality of life task takes a wider scope and does not solely focus on evaluating the AUTOPILOT pilot tests themselves, but rather aims at assessing potential impacts of AD and IoT on a more general level.

As the AD modes developed and piloted in AUTOPILOT are of a rather specific nature and their implementation differed across the pilot sites, the quality of life introduced considered more general AD mode descriptions. These allowed to better illustrate the targeted services from and end user point of view and to show the commonalities between different implementations of the services.

Of the five differentiated general AD modes in the QoL assessment, three (both Urban Driving – Signalised intersection and VRU mobile detection, as well as Highway Pilot – Hazard Detection) have a very limited focus in space and time, addressing a specific situation or event. Thus, when assessing their potential impacts on the driving procedure as a whole, their impact potential is limited. It is also not assumed that those AD modes have potential to influence the travel behaviour of users. AVP addresses a specific situation as well (the parking process), but due to the importance that the parking process has on the whole trip, its potential impacts on mobility are more far reaching. Platooning is the only AD mode with a potentially longer timeframe of use – for example, the AD mode can be enabled and active during the whole time when driving on a motorway.

As most of the AD modes tested in the AUTOPILOT pilot sites address specific locally limited issues, first the target user groups and their potential challenges, which the AD modes could mitigate, were determined to obtain a picture of the potential benefits and uses of the AD modes.

3.4.2 Automated valet parking (AVP)

3.4.2.1 Description

AVP is an automated version of valet parking, which is offered as a service for example at some airports and hotels to relieve car users from the task of finding a parking space for their vehicle, perform the parking manoeuvre and walking between the parking lot and their actual destination.

A vehicle with AVP uses data about the environment around the vehicle, for example through digital maps, positioning and information on vacant paring spots. The vehicle can use its own functions and sensors for this, but it can also benefit from access to IoT platforms, which can provide data acquired from sensors, such as parking cameras. In addition, IoT platforms can provide information on related services, such as booking and payment.

The AVP function in AUTOPILOT can drive automatically to the parking space and carry out the actual parking manoeuvre. The function typically operates at low speeds and in restricted areas (dedicated parking spaces and garages). The function can deal with obstacles and other traffic participants on the parking route. If an obstacle is detected on the route (through the IoT-connection) the vehicle is automatically rerouted. Figure 7 includes a description of the function from a user perspective, and gives an overview of the IoT aspects of the function.

Vehicle point of view

- The user reserves a parking place, drives to the drop off point and orders the vehicle to park via the app.
- The user gets out of the vehicle and continues to their appointment. Meanwhile, the vehicle drives by itself to park.
- When the user is ready to drive back home, he or she calls the vehicle back with the app, and walks to the pick-up point.
- The vehicle arrives there from the parking space.
- The user gets in and drives on.

IoT point of view

- Helps enable the service and making users aware of it
- Supervises the parking area and find free parking spaces as well as detect obstacles.
- Allows positioning in indoor parking garages
- Facilitates contact to the backend, where optimal parking spaces are determined and reserved, and route guidance for the vehicle to the parking space is calculated.

Figure 7 – Description of general AVP function.

3.4.2.2 Potential users, needs and problems

Finding a free parking space and manoeuvring the car into narrow spaces are stressful tasks for many drivers. Especially in city centres parking spaces are scarce and may be located in narrow parking garages. Many crashes occur in parking lots, and although they rarely lead to injuries, they pose economical loss and time loss for their owners. Further, people may not feel safe when using the garages for example late at night. In addition, it has been estimated that looking for parking spaces causes a considerable amount of traffic in cities.

AVP could tackle and even remove these problems by taking care of both tasks: finding a free parking space and manoeuvring the vehicle into it. It can save time for the driver and improve travel time reliability. Potential users are all car drivers, especially those less sure of their driving and parking skills. Other potential users are parking management, city planners, company/campus managers, event managers, shopping centres and car sharing services.

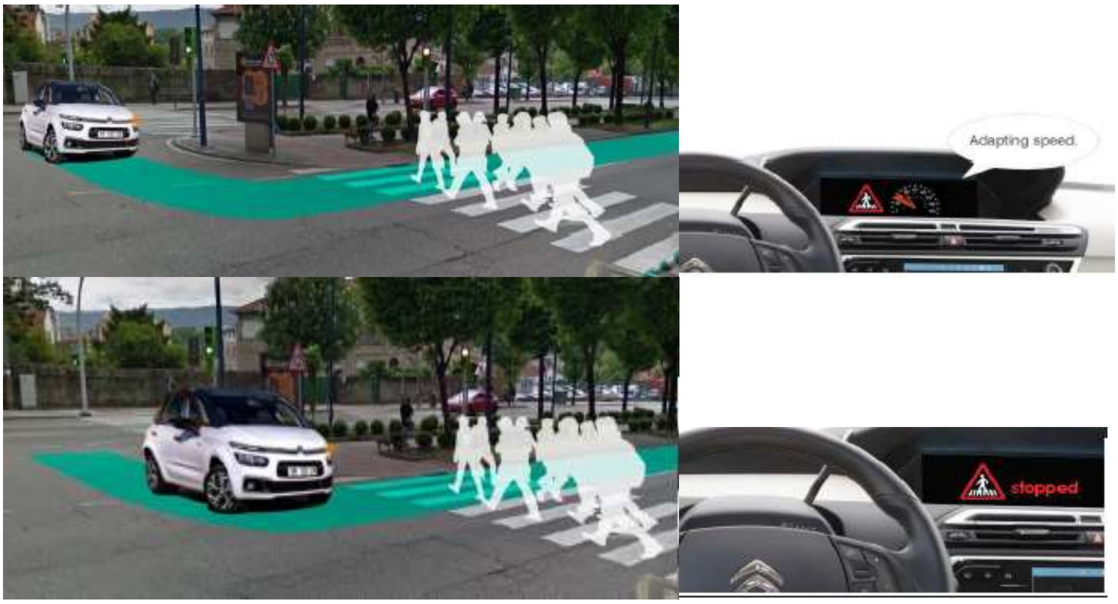
In addition to the intended, the indirect and unintended effects associated with AVP are identified and considered. Due to its convenience, it may increase car use and decrease use of public transport, especially in city centres. This may lead to increased congestion in cities, if the number of vehicles increases substantially, offsetting the gains of faster finding of parking space.
Other potential problems caused are empty spaces without people (desolation), which may arise if there are large spaces reserved only for the AVP vehicles.

3.4.3 Urban Driving – signalised intersection

3.4.3.1 Description

Urban areas are challenging environments for automated driving due to the many different road users and possible situations, which need to be handled.

The Urban driving – Signalised intersection function enables a vehicle to turn automatically from the main road to a side road at a signalised intersection in an urban area. The vehicle can drive automatically according to the traffic light status. In case a VRU is simultaneously crossing the side road, the vehicle automatically yields to him or her. Figure 8 includes a description of the function from a user perspective, and gives an overview of the IoT aspects of the function.



User experience

- The vehicle drives automatically and approaches traffic lights
- The vehicle adjusts its speed according to the traffic light status and VRU presence at the zebra crossing on the side road
    - VRU present: vehicle is warned about them, lets them cross and turns to the side road
    - No VRU present: vehicle turns to the side road

IoT-aspects

- Information about traffic light phase sent to vehicle (time to green / remaining green time)
- Vehicle can indicate that it is approaching and the traffic light will adapt
- VRU presence detected by camera and information sent to vehicle

Figure 8 – Description of AD mode Urban driving – signalised intersection.

3.4.3.2 Potential users, needs and problems

Traffic signal controlled intersections lead to a driving behaviour with a lot of braking and accelerating, and often also stops. In high traffic demand conditions this can lead to congestion and delays. From an environmental perspective, uneven travel speeds with braking and accelerating lead to more emissions, which is detrimental to air quality in cities. Intersections are also prone to accidents, especially concerning VRU as there are many conflicting paths.

Potential users and beneficiaries of the signalised intersection AD mode are drivers, especially elderly, local (regular) and commercial drivers, less experienced drivers and non-locals, bus/lorry drivers, emergency vehicle drivers. Also other road users such as VRU can benefit if the AD mode allows them to be better detected. Other benefiting stakeholders include delivery companies, local authorities, service providers, traffic management authorities, driving instructors, schools and public transport.

3.4.4 Urban Driving – VRU mobile device detection

3.4.4.1 Description

The function provides information to the vehicle about nearby VRUs or groups of VRUs, enabling for example rerouting in case of large crowds. VRU are detected through their mobile phones. In case a VRU is stepping on the road, the vehicle automatically brakes. Figure 9 includes a description of the function from a user perspective, and gives an overview of the IoT aspects of the function.

User experience	IoT-aspects
• The vehicle drives automatically in an urban environment and receives continuously information from the IoT platform / The vehicle drives in an urban environment and receives continuously information from the IoT platform • The vehicle is warned about nearby VRU's and adjust its behaviour accordingly / The driver is warned about nearby VRU's	• VRU presence detected by VRU's mobile devices and information sent to vehicle

Figure 9 – Description of AD mode Urban driving – VRU mobile device detection

3.4.4.2 Potential users, needs and problems

The problems addressed by this AD mode are detecting VRU that would otherwise not easily be detected by human drivers or vehicle sensors. Detecting large groups of VRU (crowds) in advance allows for rerouting. Upcoming traffic situations can be better anticipated and faster reacted upon. Harsh braking can be avoided by giving way more flexibly, which increases comfort and safety.

Potential users identified for the AD mode were passenger car drivers, AV itself (enhancement of sensors), bus and truck drivers, campus site managers and other local authorities and pedestrians/VRU.

3.4.5 Highway Pilot – Hazard detection

3.4.5.1 Description

The Highway Pilot AD mode explores use of IoT in context of road hazards. The term "road hazard" can include a wide range of events and situations (Mathews et al. 2019), for example road defects (potholes), stationary or slowly moving vehicles, road works, fallen objects, weather-related road changes.
Information from sensors on different IoT devices (in particular roadside cameras and other vehicles) is merged in a cloud service to locate and characterise road hazards (Schreiner et al. 2019).

The vehicle drives in automated mode on a highway, and the function warns the vehicle about upcoming obstacles or other hazards. If an obstacle is detected on the vehicle's path, the vehicle automatically adjusts its speed and the vehicle takes action to avoid the hazard. Figure 10 includes a description of the function from a user perspective, and gives an overview of the IoT aspects of the function.

User experience	IoT-aspects
• The vehicle drives automatically and receives continuously information from the IoT platform ○ Obstacle: the vehicle adjusts its speed (steering, lane change) • Proactive driving	• Road side unit (and other connected objects) detects hazards and information is sent to vehicle (extended sensing through IoT) • Cloud service merges sensor information from different IoT devices to locate and characterise hazards

Figure 10 – Description of AD mode Highway Pilot – Hazard detection.

3.4.5.2 Potential users, needs and problems

The problems identified that could be reduced with this AD mode include property damages due to potholes. Faster detection of hazards with IoT can improve rapid maintenance of the roads. Harsh braking due to potholes or other obstacles on the road can be reduced, which improves traffic safety and efficiency. More anticipative driving behaviour can be achieved.

The potential users of this service include all types of drivers as well as fleet companies and traffic management centres.

3.4.6 Platooning

3.4.6.1 Description

Platooning describes a scenario where connected vehicles follow a leading vehicle's path with a small following distance. The first vehicle can be manually driven, and the followers drive in automated mode. Platooning requires vehicles to use inter-vehicle communications (Mathews et al. 2019), so that manoeuvres of other vehicles can be anticipated and acted on.

AUTOPILOT demonstrated two use cases of platooning: on highways as well as in urban areas for allowing car rebalancing of shared vehicles between sharing stations. The QoL assessment only concerns the highway case.

The vehicles form a platoon where the leader drives manually and the following vehicles (1–4 vehicles) drive in automated mode. Figure 11 includes a description of the function from a user perspective, and gives an overview of the IoT aspects of the function.

User experience

- The user reserves a platooning place and drives to the meeting point
- The vehicles form a platoon where the leader drives manually and the followers (1–4 vehicles) drive automatically
- During the platooning the vehicles/drivers communicate with each other (setting the speed and steering)
- At the end, the vehicle dissolve the platoon and the user drives on

IoT-aspects

- Platoon formation and driving
- V2V communication
- V2I communication with traffic lights
- Integration of platooning into mobility service concept

Figure 11 – Description of AD mode Platooning.

3.4.6.2 Potential users, needs and problems

The platooning service can help with time management. For example when using the platooning service instead of one's own car when traveling to a business meeting, the travel time can be used to prepare for the meeting.

Potential users are especially the working population, for example business travellers. Also people with reduced mobility, or elderly who do not feel confident driving on motorways, may benefit.

3.4.7 Baseline used in the assessment

The potential impacts of IoT on AD are assessed by comparing connected automated driving with non-connected autonomous driving for each general AD mode. Table 3 shows the general AD modes used in QoL evaluation and the baseline they are compared with. The objective of the assessment is to explore the role of IoT for automated driving. Therefore, in order to assess the potential of IoT for AD, the baseline was chosen to represent as similar a service as possible, but without the connectivity. In the baselines chosen the vehicle is driving autonomously relying on its sensors only.

Impacts depend on level of maturity of the baseline AV function (e.g. cautious or aggressive driving style, capability to detect and react to objects, incidents etc.). Relatively cautious AV behaviour is assumed in the baseline. AD with IoT is assumed to work well (no false negatives, no disturbance in connections, etc.).

Table 3 – AD modes and Baseline used in QoL assessment.

AD mode	General use case short description (AUTOPILOT AV)	Baseline for assessment (autonomous AV)
AVP	User leaves vehicle at drop-off point, vehicle finds free parking space, drives there and parks	Automated parking with user supervision (?), user needs to assign parking space
Urban driving - Signalised intersection	Vehicle receives information on traffic light status and crossing VRUs	Vehicle relies on own sensors, no advance information on traffic light status or VRUs
Urban driving - VRU mobile device detection	Vehicle receives information on VRUs in vicinity and can reroute	Vehicle relies on own sensors, no advance information on VRUs
Highway Pilot - Hazard detection	Vehicle receives information on upcoming hazards (e.g. potholes)	Vehicle relies on own sensors, no advance information on hazards
Platooning	Following a lead vehicle by platooning, follower in automated mode	Level 3/4 motorway pilot (within its ODD)

3.5 Summary of methods

Results obtained from the relevant sources were collected on specific templates (see example in Annex 3). The aim was to find specific information on each of the boxes of Figure 1 for each AD mode, but due to the general lack of available information on AD impacts, let alone tailored to specific AD modes, this was a challenging task. Most information was found for AVP and Platooning. Information on potential changes in travel behaviour (*Behaviour and skills, Travel behaviour*) was obtained with test user surveys and focus groups.

In addition, several workshops were held with the members of the consortium.

4 Results

In the following, the results are described for each AD mode. First, the impact mechanisms where IoT could have an impact are identified and then these are mapped with each of the four impact areas (personal mobility, wellbeing, safety and traffic efficiency and environment). Finally, the potential impacts of the function are estimated, mostly in qualitative terms and quantified where possible.

While reading, it is important to keep in mind the baseline, which is autonomous (non-connected) driving. Therefore, changes that occur when shifting from manual driving to autonomous driving are not considered in the analysis. First, expected impacts of IoT on AD are described, based on the six impact mechanism boxes that make up *Mileage per mode*. Next, implications of IoT and AD on traffic safety, traffic efficiency and the environment, and personal mobility are described. Those implications are based on the data collected for each of the impact mechanism boxes and impact areas (Step 4).

4.1 Results per AD mode

4.1.1 AVP

4.1.1.1 Expected impacts of IoT

Figure 12 shows the areas of the framework (Block 2) where IoT was expected to have an impact for the AVP AD mode, compared to a non-connected autonomous parking system. These areas are elaborated below.

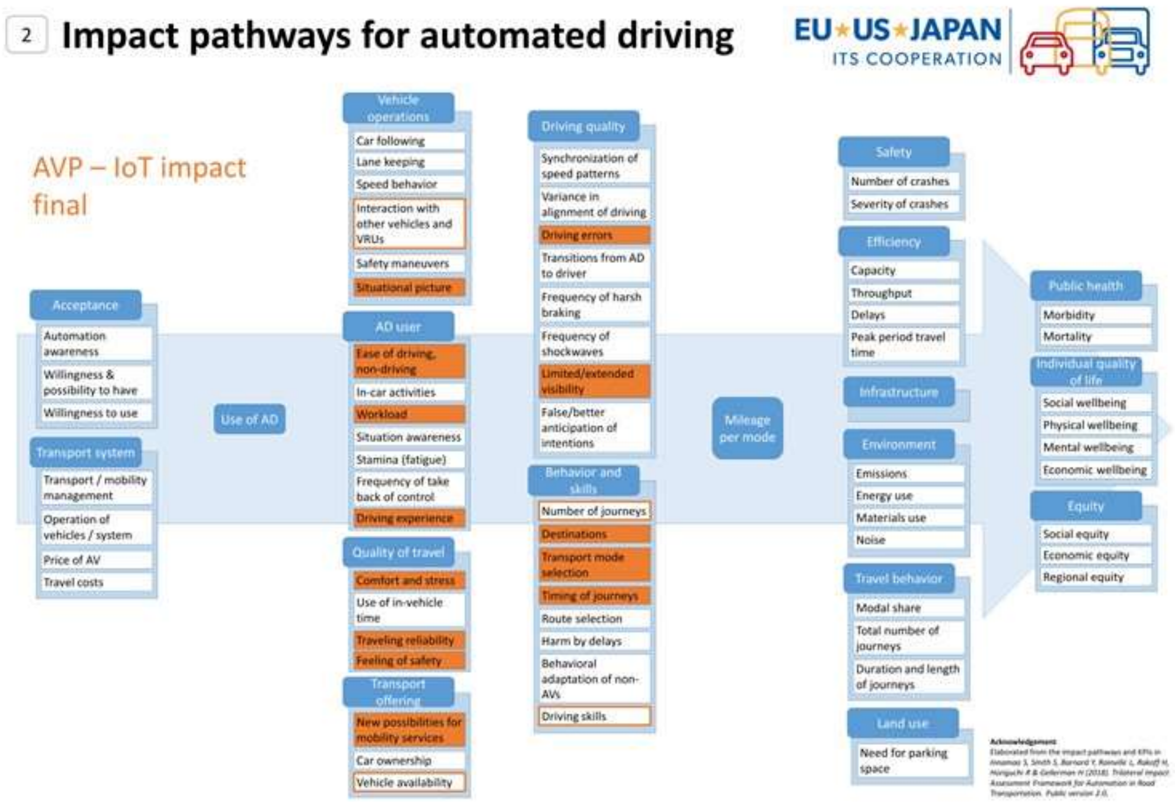


Figure 12 – Potential impact mechanisms of IoT for AVP. (Orange coloured boxes indicate direct impacts, boxes with orange borders indicate more indirect or secondary impacts.)

Vehicle operations: Compared to the baseline of autonomous parking with user supervision, minor/secondary changes are expected to *interaction with other vehicles and VRU*, mainly due to their enhanced detection via IoT devices. Relatedly, the *situational picture* of the vehicle is expected to change because IoT provides information on VRU and obstacles on the route (better path finding).

AD User: The user does not have to take care of the parking process at all (*non-driving*). The function *eases driving*, driver *workload* is no more an issue while parking and thereby, workload is reduced on the whole trip. The user does not need to park (and is not even near the vehicle during the parking) and therefore gets less *experience* with the parking task.

Quality of travel: User *stress* is expected to reduce due to the removed need for carrying out parking manoeuvres. Changes are also expected regarding *comfort* and convenience of travel. *Traveling reliability* is improved as the time for finding a parking space does not need to be estimated or taken into account. *Feeling of safety* can be improved as the user does not need to walk in or near parking lots and garages.

Transport offering: AVP has the potential of enabling creation of attractive *new mobility services* and enhancing benefits of *car ownership* for those that experience stress whilst searching for parking and/or performing parking manoeuvres. It can save time for all car users who may now benefit from being drop off directly at their destination point, thus making car ownership more attractive (and new mobility services less attractive). IoT can make this even more convenient if a user can call for their vehicle to pick up wherever they based on their mobile phone location. *Vehicle availability* can be better handled with IoT.

Driving quality: Less *driving errors* are expected as AD with IoT may be able to carry out the parking procedure more precisely. *Visibility* is extended by the use of IoT, which can inform the vehicle of obstacles that are out of reach of its own sensors.

Behaviour and skills: Due to its convenience, AVP may lead to an increase in the *number of trips* made. *Destinations* may change as it becomes easier to drive into city centres as the parking problem (finding a parking space) is eliminated. The *choice of transport mode* and *timing of journeys* may also be affected. In the long term, changes in *driving skills* can occur if the drivers do not need to use their parking skills.

In the pilot test user surveys and focus groups, many participants stated experiencing stress when parking. Especially finding a free parking spot was considered stressful.

4.1.1.2 Implications for safety

Traffic safety is affected through the mechanism topics *Vehicle operations, AD user, Driving quality* and *Behaviour and skills*, when comparing AVP to the baseline of automated parking with user supervision.

In *vehicle operations*, the situational picture of the vehicle is improved with the information received through IoT.

For *AD User*, the impacts are straight forward: due to the user not needing to take care of the parking task.

The majority of crashes related to parking involve property damages only, and the *severity* of parking crashes in form of injuries and fatalities is less prevalent. Therefore, the potential and the impacts on traffic safety are not expected to be very substantial.

4.1.1.3 Implications for Efficiency and Environment

The parking process itself does not have substantial impacts on traffic efficiency, therefore no direct impacts are expected due to AVP.

Regarding the environment, there can be impacts on a local scale, e.g. more emissions caused locally at parking garages due to more cars, but for quality of life this is considered negligible.

4.1.1.4 Implications for Personal mobility

Due to the improved comfort and convenience, AVP can have substantial impacts on personal mobility, when compared to non-connected autonomous parking. If AVP services are concentrated in highly frequented places with limited availability of parking spaces to date (such as city centres, airports, shopping centres), their attractiveness may further rise.

AVP may improve personal mobility for specific user groups, such as people with reduced mobility. For them the service allows reassurance in reaching their destination without the need for walking a long distance from the parking space.

In a majority privately owned scenario, overall car ownership may increase due to the multiple perceived benefits to the individuals. As such more space will be required for parking, even if AVP reduces the amount of space required for each vehicle.

On the other hand, in a shared ownership scenario, integrated with a comprehensive ‘Mobility as a Service’ app, AVP may offer little advantage to quality of life directly to the user. For such a system to be efficient, operators would desire that vehicles are in constant use, so vehicles would not park but go straight to the next user. This would reduce the need for parking space, but could increase empty travelling. If sharing is majority then individual car ownership would fall, thus less vehicles on the road so it is uncertain the effects on congestion within the transport system. In order to ensure vehicles are always available for the users, a surplus supply may be required and thus AVP would be advantageous.

4.1.1.5 Summary for AVP

Figure 13 shows the expected benefits of IoT and implications for traffic safety, efficiency and environment and personal mobility for the AD mode AVP.

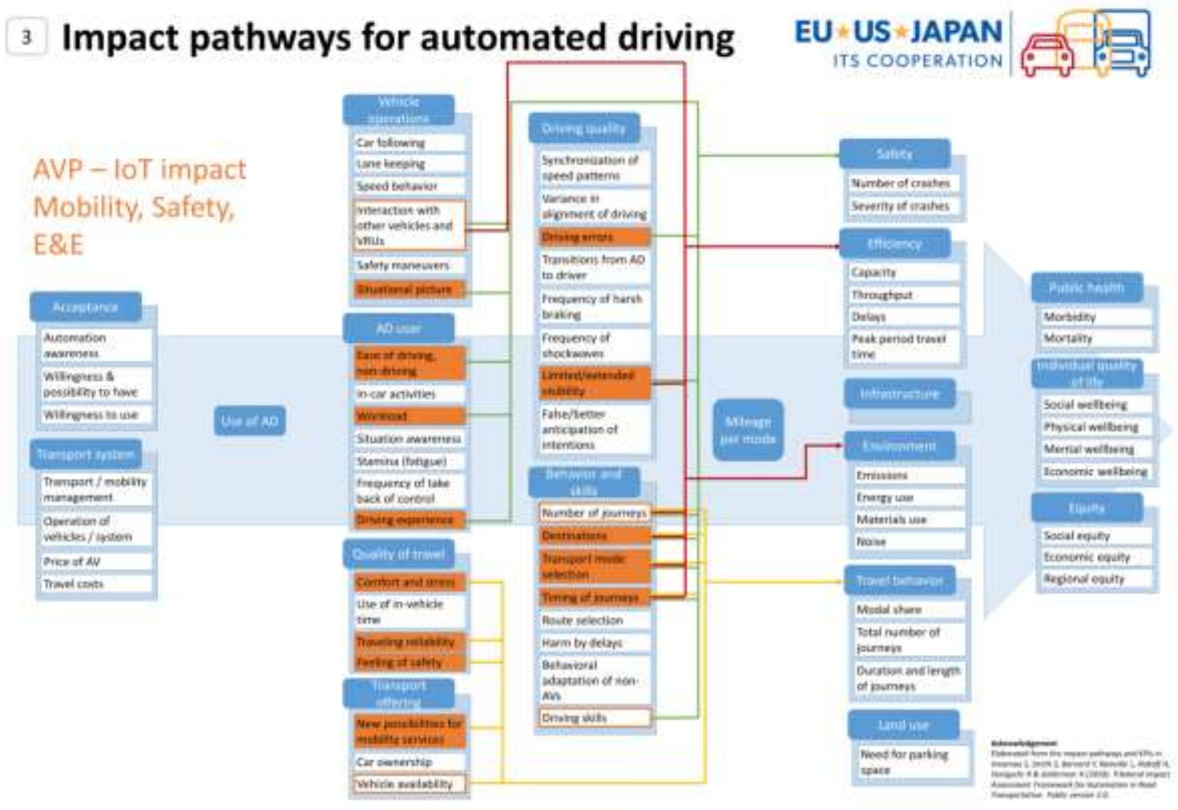


Figure 13 – Expected benefits of IoT and implications for traffic safety, efficiency and environment and personal mobility for the AD mode AVP.

4.1.2 Urban driving - Signalised intersection

4.1.2.1 Expected impacts of IoT

Figure 14 shows the areas of the framework (Block 2) where IoT was expected to have an impact for the Urban driving – Signalised intersection AD mode, compared to non-connected autonomous driving. These areas are elaborated below.

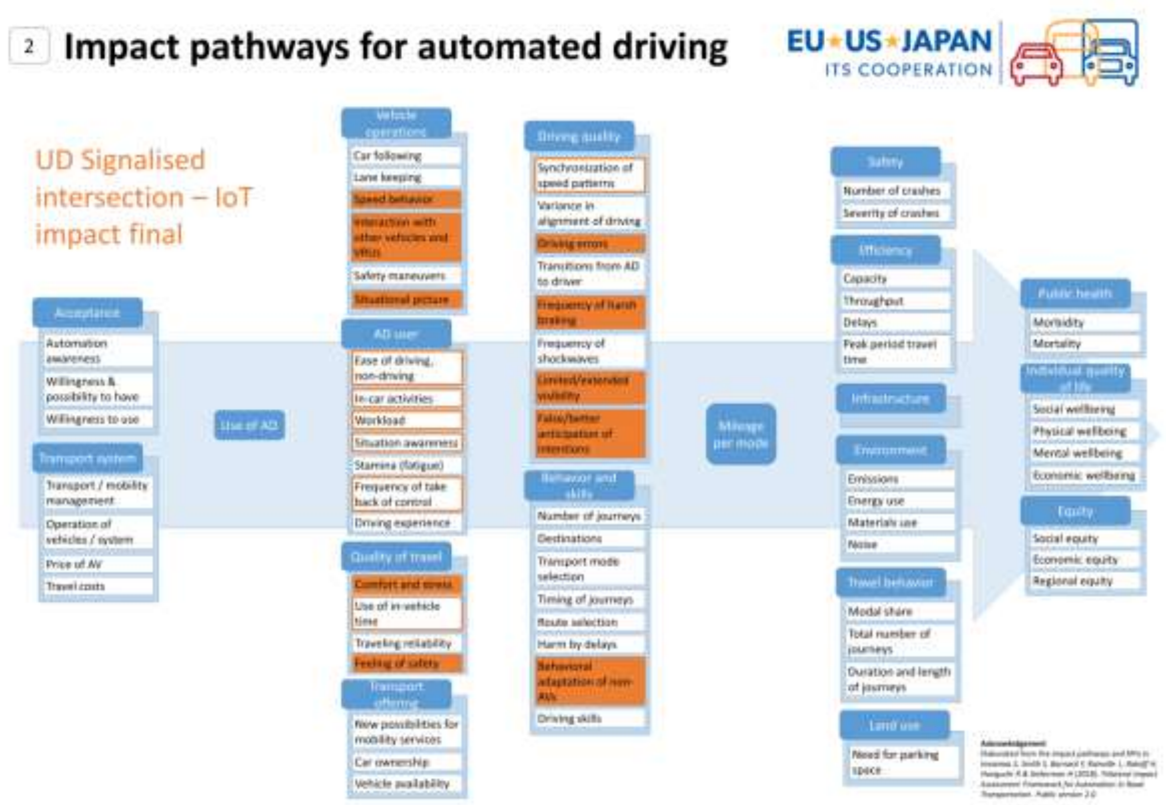


Figure 14 – Potential impact mechanisms of IoT for Urban driving – Signalised intersection. (Orange coloured boxes indicate direct impacts, boxes with orange borders indicate more indirect or secondary impacts.)

Vehicle operations: The *Speed behaviour* of vehicles is expected to change due to IoT, as the vehicle with this AD mode receives information on traffic light status and potential VRU wanting to cross. The maximum driving speed near the intersection is expected to decrease as information of speed limits is more precise and adherence better. Due to anticipation driving becomes smoother and variance of speed decreases. Inter*action with other vehicles and VRU* changes as VRU detection at intersections is improved with the IoT cameras. This also affects the *situational picture* of the vehicle.

AD User: The AD user aspects are indirectly affected by IoT. There may be changes to *ease of driving*, *in-car activities, workload, situation awareness* and *frequency of take back of control*, when compared to non-connected automated driving, but as the scope of the use case is narrow (an intersection) these changes are assumed to be minor/secondary.

Quality of travel: *Comfort* is expected to change due to different driving style of the vehicle in the intersection (i.e. possibly smoother driving). *Stress* may change due to enhanced detection of VRU. This may also affect the users' *feeling of safety*. Minor changes are expected on *use of in-vehicle time*.

Transport offering: No changes are expected for this driving mode due to IoT.

Driving quality: *Synchronisation of speed patterns* may have minor impacts if vehicles drive more smoothly through intersections. IoT provides *extended visibility*, and *driving errors* are expected to change due to enhanced anticipation with IoT. Also changes in *anticipation of intentions* of other road users can be expected. Further, changes are expected to the *frequency of harsh braking*.

Behaviour and skills: *Behavioural adaptation of non-AVs* may occur in two ways: drivers of conventional vehicles might imitate behaviour of CAV in intersections, and VRU may show more careless behaviour when crossing the traffic lights if they learn to rely on being detected by IoT.

4.1.2.2 Implications for safety

The safety impact mechanisms where IoT was expected to have an effect compared to unconnected automated driving were related to *Vehicle operations*, *AD user, Driving quality* and *Behaviour and skills*.

The mechanisms under *Vehicle operations* were speed behaviour, interaction with other vehicles and VRUs and situational picture. Speed behaviour's safety impact mainly depends on the driving style and speed level itself. If the speed level is lower, safety improves mainly due to longer time for reaction, shorter braking distance and lower impact speed. The safety impacts of interaction with other vehicles and VRU's also depend largely on the behaviour of the vehicle i.e. are there standstills or misjudgements between road users (due to e.g. yielding behaviour, intent communication). A large share of users (42 –72 %) at the user tests involving a pedestrian crossing felt uncomfortable by the following aspects: distance kept to pedestrians and cyclists, and behaviour when approaching pedestrians and cyclists at intersection. Situational picture refers to a more reliable detection of VRUs since the vehicle is warned before entering the pedestrian crossing. According to a recent study by AAA (2019) on sensor-based pedestrian detection systems, none of the test vehicles applied automatic braking in the scenario with a pedestrian target directly after a right curve. Hence, the function could improve safety since the vehicles' situational picture is improved. To summarise, *Vehicle operations* can improve safety due to improved situational picture and different speed behaviour. Although depending on the functionality (communication of intentions, yielding behaviour etc.) there might be some issues arising from the interaction between other vehicles and VRUs.

The mechanisms under *AD user* (ease of driving, non-driving; in-car activities; workload; situation awareness; frequency of take back control) were identified to be indirectly influenced by the function. All of the topics were not included in the user test surveys and the tests themselves were not extensive enough to draw any overall conclusions. However, most users found the experience positive, safe and useful and the service relaxing and exciting. Although simultaneously a majority found the driving behaviour uncomfortable, in many cases, the users felt that the technologies were not mature enough. All in all the impact mechanisms under *AD user* are more subjective impacts and since the functionality is very limited, the impact on objective safety is most likely small.

The impact mechanisms under *Driving quality* were synchronisation of speed patterns (indirect), driving errors, frequency of harsh brakings, limited/extended visibility and false/better anticipation of intentions. No estimate of the magnitude of impacts was found but safety was expected to be improved due to extended visibility, better anticipation of intentions, decrease in harsh brakings, decrease in driving errors and synchronisation of speed patterns. Although the impacts largely depend on the driving style: negative impacts are also possible e.g. if the driving style becomes less smooth.

For *Behaviour and skills*, the only identified impact mechanism was behavioural adaption of non-AVs. As regards to safety, the impacts are most likely more negative than positive for example because VRUs might start expecting that all cars will yield to them and other vehicles might start misusing their yielding rights. On the other hand other vehicles may also start yielding better to VRUs. Overall, traffic safety can be expected to deteriorate, slightly since the scope of the function is so limited, due to behavioural adaptation of VRUs and other vehicles.

4.1.2.3 Implications for Efficiency and Environment

The impact mechanisms related to efficiency and environment where IoT was expected to have an effect compared to unconnected automated driving were related to *Vehicle operations*, *Driving quality* and *Behaviour and skills*.

The impact mechanisms under *Vehicle operations* were speed behaviour and interaction with other vehicles and VRUs. For both mechanisms the impacts largely depend on the chosen driving style (speed level, smoothness, yielding behaviour etc.). If the speed level is lower and speed behaviour smoother, traffic efficiency and environmental impacts can be expected to improve due to decreased fuel consumption. Although depending on the functionality (communication of intentions, yielding behaviour etc.) there might be some issues from the interaction between other vehicles and VRU's.

The impact mechanisms under *Driving quality* were synchronisation of speed patterns (indirect), frequency of harsh brakings and limited/extended visibility. Similar to safety, the impacts on efficiency and environment largely depend on the driving style: it is expected to improve if smoother driving (decrease in harsh brakings, extended visibility, more synchronised speed patterns). For example, fuel consumption has been found to be halved with V2I communications (Eilbert et al. 2018).

For *Behaviour and skills*, the only identified impact mechanisms was behavioural adaption of non-AV's which in itself does not have a large impact on efficiency and environment since the scope of the function is so limited.

In summary, the *Signalised intersection* AD mode is expected to provide benefits for the environment (reduced emissions). Impacts on traffic efficiency are assumed negligible.

4.1.2.4 Implications for Personal mobility

For the personal mobility, the impact mechanisms where IoT was expected to have an effect compared to unconnected automated driving were related to *Quality of travel* (comfort and stress, feeling of safety and use of in-vehicle time).

A majority of user test participants indicated in the survey that their comfort and stress would decrease. Several studies have also found that advanced automated driving and infotainment systems can increase the comfort of driving (Gerla et al. 2014, Kolarova et al. 2019, Lemmer, 2019, Pakusch et al. 2018) and reduce stress (e.g. Daschkovska et al. Kolarova et al. 2019; Singleton, 2017, Singleton, 2019). On the other hand they can also increase boredom, loss of driving pleasure (Fraedrich et al. 2016; Pudāne et al. 2019; Trommer et al. 2017), loss of control, risk of malfunction (Kolarova et al. 2019).

The AD mode itself is not expected to change the use of in-vehicle time substantially compared to unconnected AD due to the limited scope of its functionality.

As regards feeling of safety, most users indicated improvement (e.g. increased visibility). The participants were more worried of safety of passengers and driver inside the vehicle compared to the safety of other road users.

To summarise, UD-SI's main implication on personal mobility is that journey quality is improved and this can increase the attractiveness to use the AD mode or the personal car in general. No reasoning was found for changes in the number of journeys or their duration and length.

4.1.2.5 Summary for Urban driving – Signalised intersection

Figure 15 shows the expected benefits of IoT and implications for traffic safety, efficiency and environment and personal mobility for the AD mode Urban driving – Signalised intersection.

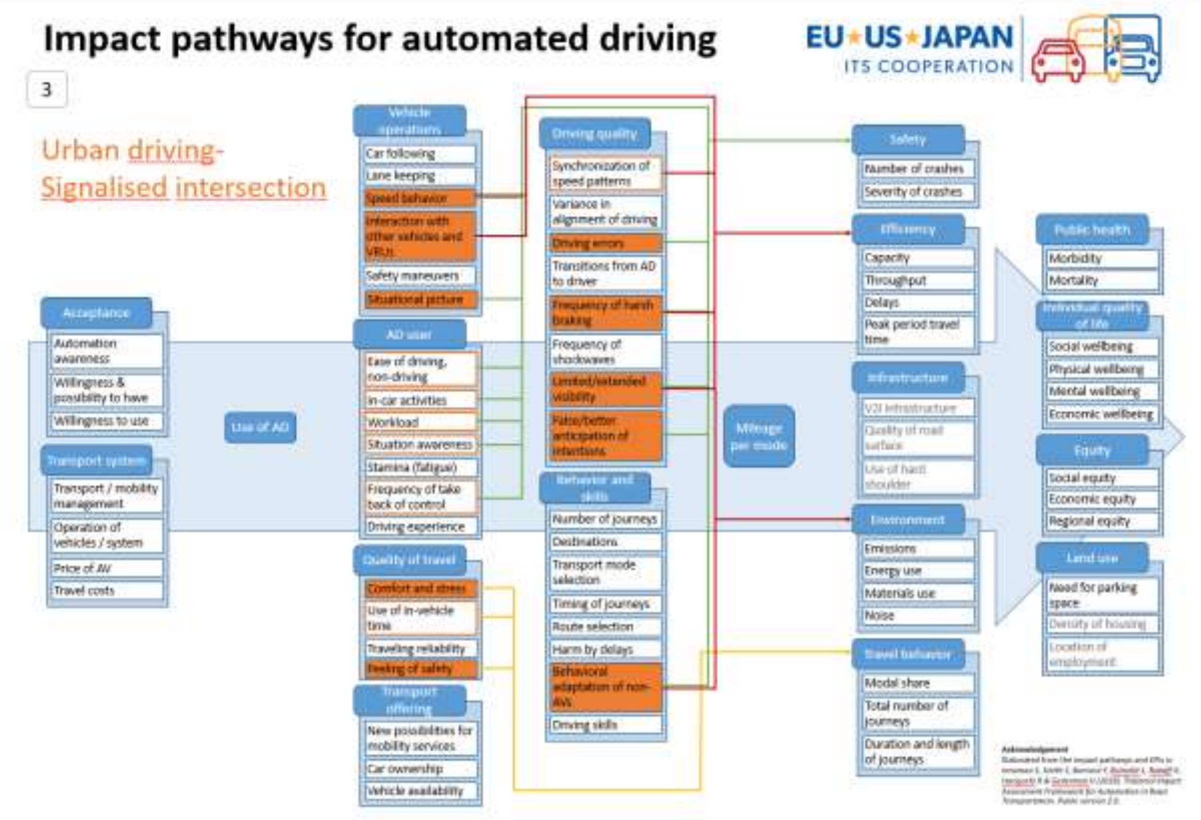


Figure 15 – Expected benefits of IoT and implications for traffic safety, efficiency and environment and personal mobility for the AD mode Urban driving – Signalised intersection.

4.1.3 UD – VRU mobile device detection

4.1.3.1 Expected impacts of IoT

Figure 16 shows the areas of the framework (Block 2) where IoT was expected to have an impact for the Urban driving – VRU mobile device detection AD mode, compared to non-connected autonomous driving. These areas are elaborated below.

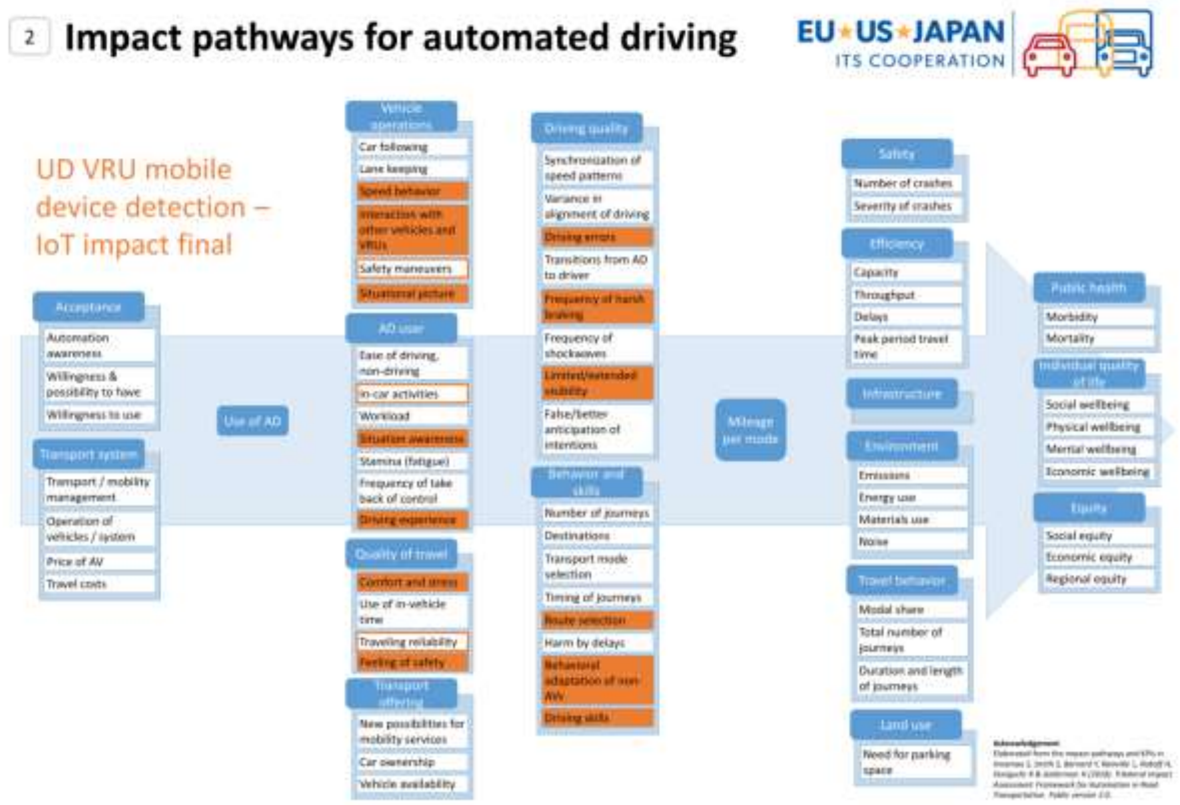


Figure 16 – Potential impact mechanisms of IoT for Urban driving – mobile device detection. (Orange coloured boxes indicate direct impacts, boxes with orange borders indicate more indirect or secondary impacts.)

Vehicle operations: With the use of IoT to detect pedestrians and crowds, changes are expected to *Speed behaviour, Interaction with other vehicles and VRUs* and the *Situational picture*. In case of sudden hazardous situation, it may also enable the vehicle to execute *Safety manoeuvres* more appropriately.

Mobile devices used by VRU can transmit the location and movement information of their users to the connected vehicles via IoT. This improves the *situational picture* of the vehicle, because VRUs can be detected at longer range and beyond obstacles. With more extensive and accurate position information, the system can better predict on-coming situations. Better prediction of VRUs will help to match the *Speed behaviour* to the traffic situation, and make *Interaction with other vehicles and VRUs* smoother. In case of a sudden hazardous situation, it may also enable the vehicle to execute *Safety manoeuvres* more appropriately.

Predictions can be used to either guide the self-driving vehicle, or to supply warnings either to the driver or other road users (e.g. Gustafsson et al. 2013). Fusing information from the crowds of VRUs can also provide information about VRU flows (cf. Krytska et al. 2017), which supply information on traffic flow and its problems (e.g. congestion).

AD User: The users' *Situational awareness* is expected to change, if the user is informed on the VRU via an HMI. This information probably makes situation awareness more accurate. However, it is possible that users become over-reliant on the system, especially if the system is near perfect. Consequently, they may stop looking for VRUs themselves. This may decrease their hazard perception abilities. This will change their *Driving experience*, as they have less experience dealing with situations, which require anticipation of VRUs. The reliance on VRU detection may also be reflected in the increase of *In-car activities.*

Quality of travel: *Comfort and stress* of the drivers can change, when the interaction with VRUs becomes smoother, as well as their *Feeling of safety* if the interaction is perceived to be safer. There may be minor positive impacts to *Travelling reliability*, e.g. due to the ability to reroute vehicles away from areas with high VRU flows.

Some findings regarding quality of travel were made in the pilot tests. While these findings cannot directly be generalised due to the pilot limitations, they can provide some indication on the potential. Over three quarters of users found the experience (IoT/AD) comfortable with at least one participant mentioning discomfort at one point or another during the session. The vehicle behaviour (e.g. accelerating, abrupt braking) were the most common sources of complaint, leaving some participants with the feeling that the 'human touch' is missing. Experiencing the artificiality of the system during the testing session, as eloquently put by a participant, it needs more of a 'human touch'. In Versailles, smoothness of ride was perceived more positively, where in Tampere most participants (20/27) rate the ride smoothness as uncomfortable. The context and system differ from one site to the other, therefore the results cannot be compared. In Versailles, direct comparison between the baseline (AD) and (IoT/AD) conditions resulted in Versailles: Users were aware of braking because of the pedestrian and/ or bicycle and participants stated that the IoT enhanced VRU detection happened with smoother braking, hence users were aware of the events and how they were related to the VRU detection. The only question we can related to situation awareness is vigilance and vigilance was rated and only one user thought the system was sleep inducing, either with or without IoT (i.e. IoT condition was only 0.2 score higher than with IoT condition). Vigilance is between 0.5 and 0.7 (-2 to 2 scale).

Taking into consideration that the IoT condition always followed the non-IoT one, this finding is interesting. The perceived smoothness of the second ride, slightly lower the sleep-inducing effect of this ride. In reality, the opposite would be expected. Changes are so small, though, that the differences can be related to any factors (e.g. the test session finishes).
Stress was slightly alleviated post-test when compared to pre-testing, but all in all ratings were positive in both Tampere and Versailles.

Trust in the system and increase in sensitivity is important for travellers when using any system and even more when the system detects other road users. Reliability of information and its provision is more important than travelling reliability and comes first, i.e. the information provided needs to be accurate, to be received on time in order to technology to be used. Travelling reliability is not anticipated to affect much the travel times and delays. Potential delays might happen because of re-routes but even these are not anticipated to be a considerable to notice magnitude. These small effects on certain road conditions and scenarios, i.e. situations where VRU detection safety issues might arise (unsignalised intersections, zebra crossing, busy urban centres like shopping areas, etc., can be escalated into a larger impact on traffic harmonisation of flow and relief of congestions. Therefore, the effect on personal travelling reliability will be small but when scaling it up on a traffic environment level, the efficiency of the traffic system might be improved.

Detection of hazards, obstacles and other road users is a crucial and very error-prone aspect of the driving task. Participants rated the systems as safe. This area was the most positive with least concerns. Higher concerns were reported about the drivers and passengers inside the vehicle. It is anticipated that the deployment of service will increase safety.

Overall, travel quality is improved on a hedonic level but travel efficiency increases are very small on a personal level. Increase in the latter should be viewed from a macroscopic traffic perspective.

Transport offering: No changes are expected for this AD mode due to IoT.

Driving quality: Changes are expected to *Driving errors, Frequency of harsh braking* and *Extended visibility* with IoT. These are due to the improved *Situation picture,* which will help the vehicle/user to perform the correct manoeuvre well in advance, and avoid critical situations, and increase perceived safety (e.g. Versailles user testing).

Behaviour and skills: Changes are expected to *Route selection* as AVs can reroute in case of VRU crowd detected ahead), which may lead to users not avoiding urban and complex driving contexts, conditions and environments, as some might do today. Accordingly, the complexity and the length of routes might increase, but the expected impact is not expected to be substantial for personal mobility choices. *Behavioural adaptation of non-AVs* (change in VRU behaviour if they become confident that the AV gives them way) is possible. VRUs may "learn" to push the limits of AVs (stepping out, knowing it will stop etc.), which may increase hazardous situations (Rämä et al. 2018). On the other hand, this may increase the drivers' need to be aware about VRUs, especially pedestrians. Over time, the lack of driving experience in certain situations may lead to deterioration of *Driving skills*.

4.1.3.2 Implications for safety

Vehicle's Improved *Situational picture* as well improvements in driver's *Situational awareness* are likely to increase safety of VRUs, by reducing the number of potentially hazardous situations. More *appropriate Safety manoeuvres* may reduce the number of crashes or mitigating their severity. More appropriate speeds (that is, lower speeds) will also reduce the severity of crashes if one happens. Potential decrease in *Driving skill*s may on the other hand deteriorate traffic safety in manual driving situations. Similar influence is with *Behavioural adaptation* of non-AVs: if they start to expect that IoT connected AVs can detect them always, they may start to move less carefully.

4.1.3.3 Implications for Efficiency and Environment

Improved understanding of the VRU flows will allow the AVs to choose congestion free routes and also to match their speeds better to traffic gaps. This can slightly improve efficiency of the traffic and have environmental benefits. On the other hand, rerouting may lead to a longer distance travelled. However, the size of these impacts is not expected to be large.

4.1.3.4 Implications for Personal mobility

By improving the actual (or perceived) safety of VRUs, IoT connected AVs could make active transportation modes as well as using light-vehicles more attractive (Noland, 1995). Such a change may have complex implications. For example, increase in active transportation modes may improve public health (Oja et al. 2011) and make cities more liveable environments for all. On the other hands, when the modal share of e.g. cycling increases, it may also increase the absolute number of accidents, even though the relative risk decreases. Also driving can become less stress free, making it a more pleasant experience for those, who at the moment avoid driving in the cities. Overall, there changes may increase people's mobility, as it is safer and more comfortable.

In the pilot tests, changes in mobility patterns were not expected, apart from Versailles UD pilot. When users take up the role of tourist, as it was the case for the French pilot site, they expect increase in walking/cycling, increase in use of public transport and decrease in passenger car use. Personal mobility is not expected to be directly affected but the interaction and experience of the interaction with other VRUs will probably be different.

4.1.3.5 Summary for Urban driving – VRU mobile device detection

Figure 17 shows the expected benefits of IoT and implications for traffic safety, efficiency and environment and personal mobility for the AD mode Urban driving – VRU mobile device detection.

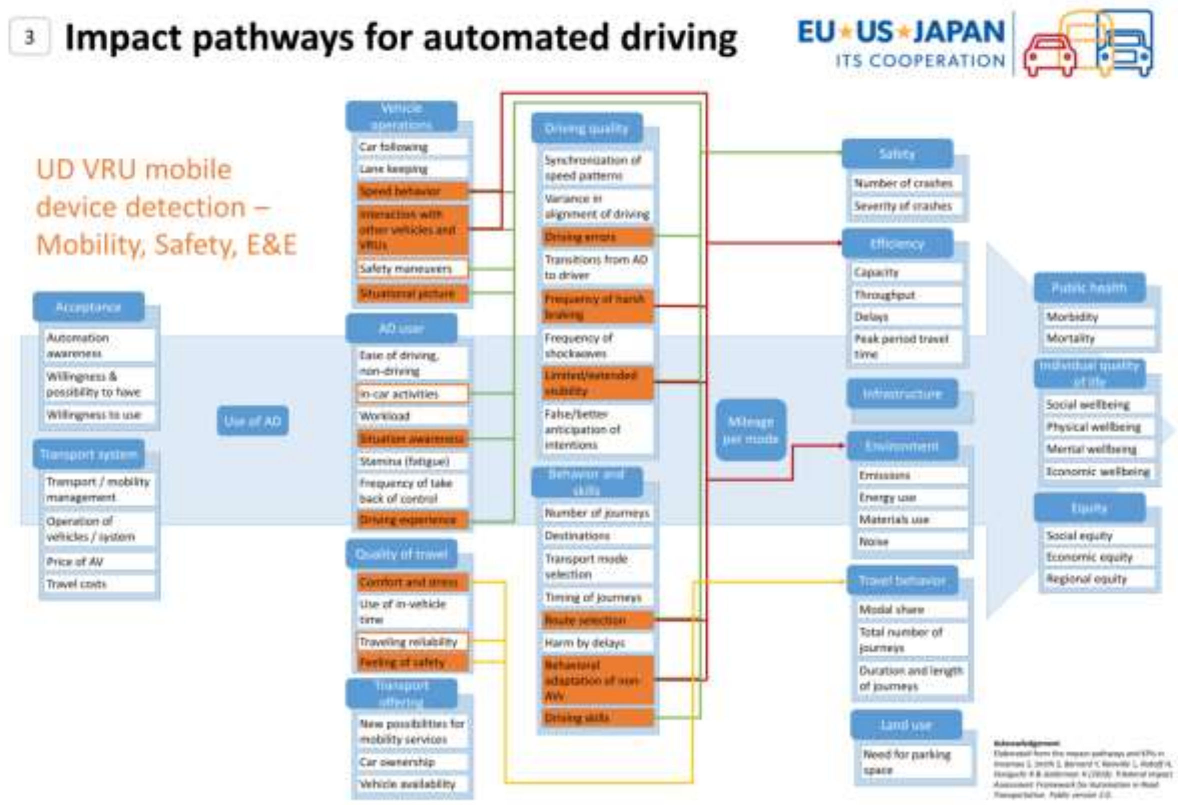


Figure 17 – Expected benefits of IoT and implications for traffic safety, efficiency and environment and personal mobility for the AD mode Urban driving – VRU mobile detection.

4.1.4 Highway Pilot – Hazard detection

4.1.4.1 Expected impacts of IoT

Figure 18 shows the areas of the framework (Block 2) where IoT was expected to have an impact for the Highway pilot – Hazard detection AD mode, compared to non-connected autonomous driving. These areas are elaborated below.

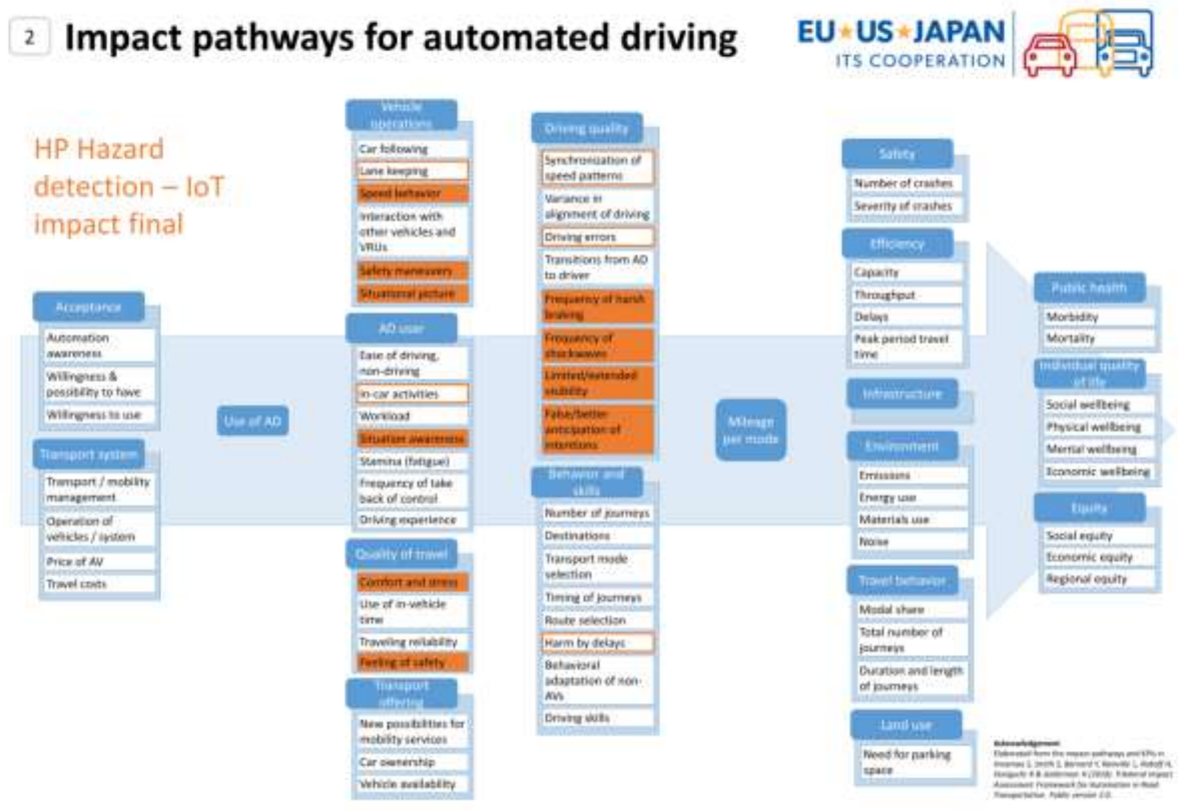


Figure 18 – Potential impact mechanisms of IoT for Highway Pilot – Hazard detection. (Orange coloured boxes indicate direct impacts, boxes with orange borders indicate more indirect or secondary impacts.)

The change in the AV service related to the Hazard detection function would be the following (compared with AD without connectivity):

- The vehicles would receive more information about hazards as the type and number of sources increases - the amount of information increases
  - Hazards would be better covered
  - Possibly new type of hazards would be covered: obstacles, incidents, road surface condition, stopped cars, jams…
  - Notifications and reactions of the vehicle (e.g. braking) would be more frequent
- Hazards would be anticipated better - AV would receive the information earlier
  - Several sources (V2V and V2I) and connectivity would increase perception distance upstream
- Reliability of AD service would increase
  - Several information sources could be used in confirming the perceptions
  - More information but not increase (less) in false alarms

All above is expected to increase acceptance of Hazard detection function as part of AVs, to increase drivers' willingness to purchase the functionality and also use it. The function would be used more frequently and the use would cover a variety of road types, areas and circumstances. Consequently, the penetration of the Hazard detection function in the actual traffic flow would be bigger than without IoT. In case the price of the IoT based Hazard detection function (share of the price of the car) becomes very high the willingness to purchase is less.

In the participant interviews, some comments were received to indicate that users had noticed the obstacles and potholes due to Hazard detection function.

The Hazard detection function is targeted to all car drivers in highways. The recent ecoDriver project (2011-2014, Carsten et al. 2016) estimated that approx. 17% of vehicle km's in Europe were in highways and the share of km's by car was approx. 79%. Assuming that all cars are equipped and the function is used 80% of time leads to an estimate of 10.7% (17 x 79 x 80) which should be considered as a coefficient for any total effects (see also Rämä et al. 2018). Moreover, the frequency of hazards needs to be taken into consideration. The estimate gives insight to the potential of impacts of a highway autopilot designed for cars.

Vehicle operations: Changes are expected to *Speed behaviour* of the vehicles as well as *Car following* behaviour. Several studies regarding driver informative ITS services have showed decrease in mean speed and increase in time headways between vehicles for example, C-ITS field studies (Malone et al. 2014) and expert assessments (Kulmala et al. 2008, Wilmink et al. 2008, Rämä et al. 2018) and field studies variable message sign (Rämä and Kulmala 2000). Previous studies suggest that the impacts would be more substantial in case of an intervening system (such as automation) compared to the informative systems (e.g. Carsten and Tate 2005). Moreover, it is reasonable to assume that the impacts would be bigger because the hazards are covered better by IoT. *Situational picture*, due to receiving information on hazards ahead would be improved in two ways - on one hand the traffic management would have a better situational picture due to many information sources, and on the other hand the drivers could share information in vicinity of own vehicle. It is assumed that the vehicle would react automatically to many hazards, for example by braking, and in that respect *safety manoeuvres* may be more quick and harmonized as they would be less in the control of the human actor who are assumed to have more variation in reactions (e.g. reaction time).

AD User: If the users are informed about the hazards ahead, their *situation awareness* changes. Critical for the situation awareness is the timing of observation and thereby, possibility to react to the hazards anticipatory. IoT enhances the early detection of hazards. The hazard detection functionality may have minor influence on *in-car activities*. The driver may engage to other tasks than the primary driving task. This would be feasible in case validity and reliability of the hazard detection system is very high. In addition, IoT may enhance fluency of handovers as the early detection gives more time in case of encountering a hazard.

Quality of travel: *Comfort and stress* of the user are expected to be improved by IoT and hazard detection - due to early warnings abrupt decelerations could be avoided. In addition, a more general awareness of the hazard detection are assumed to contribute in decreasing stress related to driving. The users' *feeling of safety* in AVs is likely to be improved as well.

Transport offering: No changes are expected for this AD mode due to IoT.

Driving quality: Due to the detection of hazards in advance, changes to driving behaviour are expected, which leads to changes in traffic flow (more smooth). Decrease in *frequency of harsh braking* and in *frequency of shockwaves, extended visibility* and *better anticipation of intentions* are expected due to more early information on hazards and improved communication between parties. Further, some decrease is expected in *driving errors* because of more time to react is given and automated manoeuvring of the vehicle. Minor indirect changes through *synchronisation of speed patterns* when majority of vehicles share the same information is assumed.

Behaviour and skills: Minor/indirect changes are expected to *harm by delays*, due to the changes in traffic flow *driving errors* and because drivers would be better aware of the causes of the delays.

4.1.4.2 Implications for safety

In this chapter safety impacts resulting from changes in ‘Vehicle operations’, ‘AD user’ and ‘driving quality’ are addressed. In addition, safety is influenced by changes in travel behaviour (e.g. number of journeys and route choice). All indirect and secondary impacts are not discussed in detail.

Number of crashes is related to the *speed* (Nilsson 2004) and the risk of crash varies by road type (Elvik et al. 2019). The evidence for Nilsson’s Power Model comes from manual driving and the model may need some updates for the automated road transport. Still, it is assumed that speed is associated with crash risk also in automated driving. The evidence regarding the relationship of number of crashes and headway - *car following* - is not that strong. However, very short driving distances are associated with increase in risk of a crash. Based on earlier ITS studies (impacts of C-ITS Malone et al. 2014, impacts of VMS Rämä 2001) it is assumed that speed would decrease and headways increase due to improved hazard detection. Expert assessments, as well as ISA studies (Carsten and Tate 2005), have suggested that the effect is more substantial in case of an intervening system compared to informing systems. In case of AUTOPILOT it is assumed that hazards detected reliably would affect directly the controls of the AV. An estimate of the reliability should be combined with system penetration in traffic flow taking into consideration several factors influencing the penetration (Rämä et al. 2018).

Severity of crashes is related to speed, and would decrease due to hazard detection. In urban area, speed affects substantially on the consequences if a vulnerable road user is hit by the car. However, in AUTOPILOT hazard detection was applied mostly in highways. In addition, applying IoT based hazard warning may affect crash type distribution. Moreover, new type of crashes may evolve, not known yet.

4.1.4.3 Implications for Efficiency and Environment

The amount of *emissions* and *use of energy* is directly dependent on the distance driven. Automation has potential to decrease emissions and use of energy as it may be more feasible to optimize driving speeds and have a more smooth traffic flow, less accelerations and decelerations, and stop and go type driving. This would also contribute in better throughput in traffic flow.

Hazard detection is assumed to have small impact on *use of materials.* The function would prevent more efficiently than AD driving in potholes causing damages to the vehicles.

The impacts on *noise* are not expected to be substantial.

4.1.4.4 Implications for Personal mobility

For *travel behaviour* the most substantial impacts are assumed resulting from changes in *comfort and stress* and in *feeling of safety*.

Regarding *modal share* it is expected that the share of private cars in modal split would increase. Some user studies indicate that the introduction of automation in cars may increase *comfort* of car driving (Gerla et al. 2014, Kolarova et al. 2019, Lemmer, 2019, Pakusch et al. 2018) and reduce *stress* related to driving (Daschkovska et al. Kolarova et al. 2019; Singleton, 2017, Singleton, 2019). The hazard detection is expected to contribute in this because people probably *feel more safe* and comfortable when they are aware that the will be and are warned about potential hazards, provided that the warnings are not too frequent and that they are reliable and understandable from user point of view. In case of very frequent warnings driving would be less comfortable and the service would be turned off.

Some results indicate that users may experience loss of driving pleasure which would lead to smaller shares of car use (Lemmer 2019). It is supposed that warnings about hazards would not influence on pleasure of driving.

No reasoning was found for changes in the *number of trips.*

Duration of journeys may be shorter in case there are alternative routes to avoid encountering the hazard perceived and warned about. *Harm by* delays would be less due to the alternative route which would be shorter in time but also because of knowing better the reason for the delay. In many cases, the alternative route can be *longer* in km as part of the journey originally planned. The effect is not assumed to be big because very long alternative routes would not be used.

IoT based hazard detection is expected to support delivering information not only during the journey but before it starts which may affect timing of journey and due to that duration of the trip. Driver information studies (e.g. Sihvola 2009) have indicated information on hazards may change plans regarding timing of the trip. The trip can be cancelled or shortened or the driver can decide to have a break due to the hazard. Wide scale automation and IoT could improve traffic management and thereby enhance the optimal use of road network in case of a hazard.

4.1.4.5 Summary for Highway pilot – Hazard detection

Figure 19 shows the expected benefits of IoT and implications for traffic safety, efficiency and environment and personal mobility for the AD mode Highway pilot – Hazard detection.

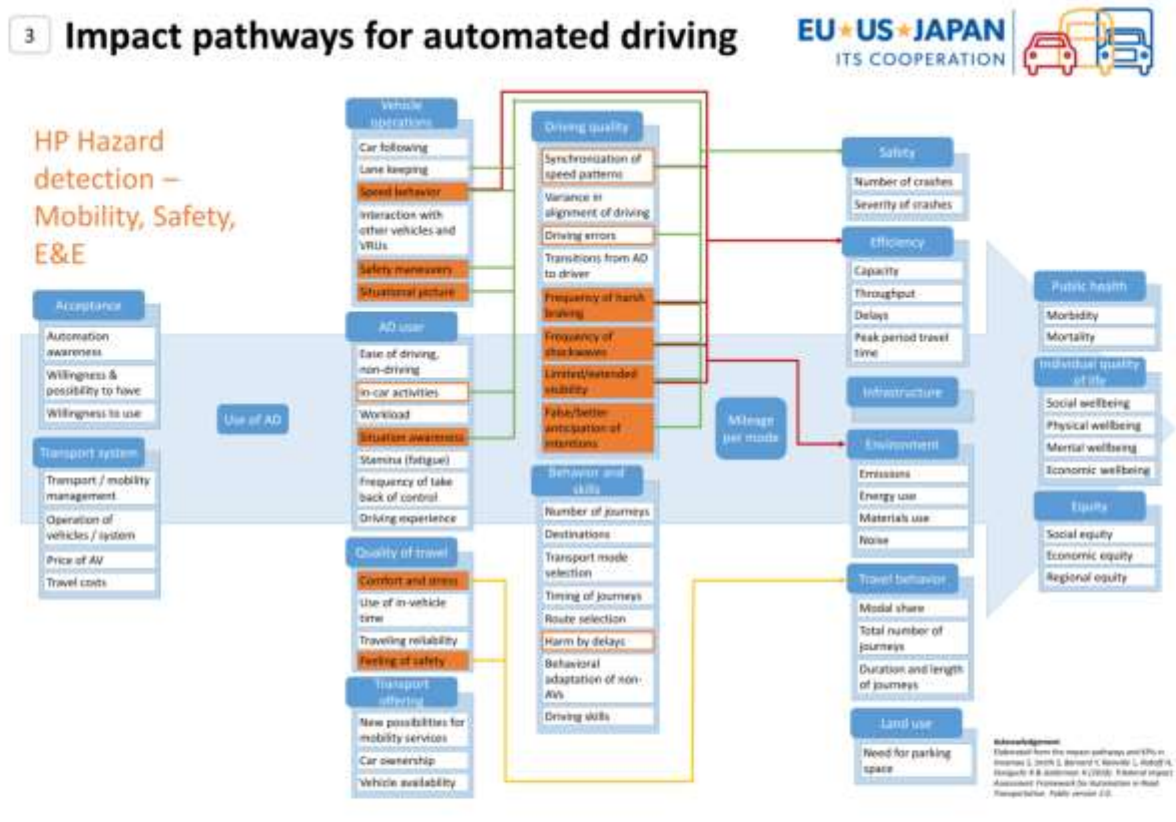


Figure 19 – Expected benefits of IoT and implications for traffic safety, efficiency and environment and personal mobility for the AD mode Highway Pilot – Hazard detection.

4.1.5 Platooning

4.1.5.1 Expected impacts of IoT

Figure 20 shows the areas of the framework (Block 2) where IoT was expected to have an impact for the Platooning AD mode, compared to non-connected autonomous driving. These areas are elaborated below.

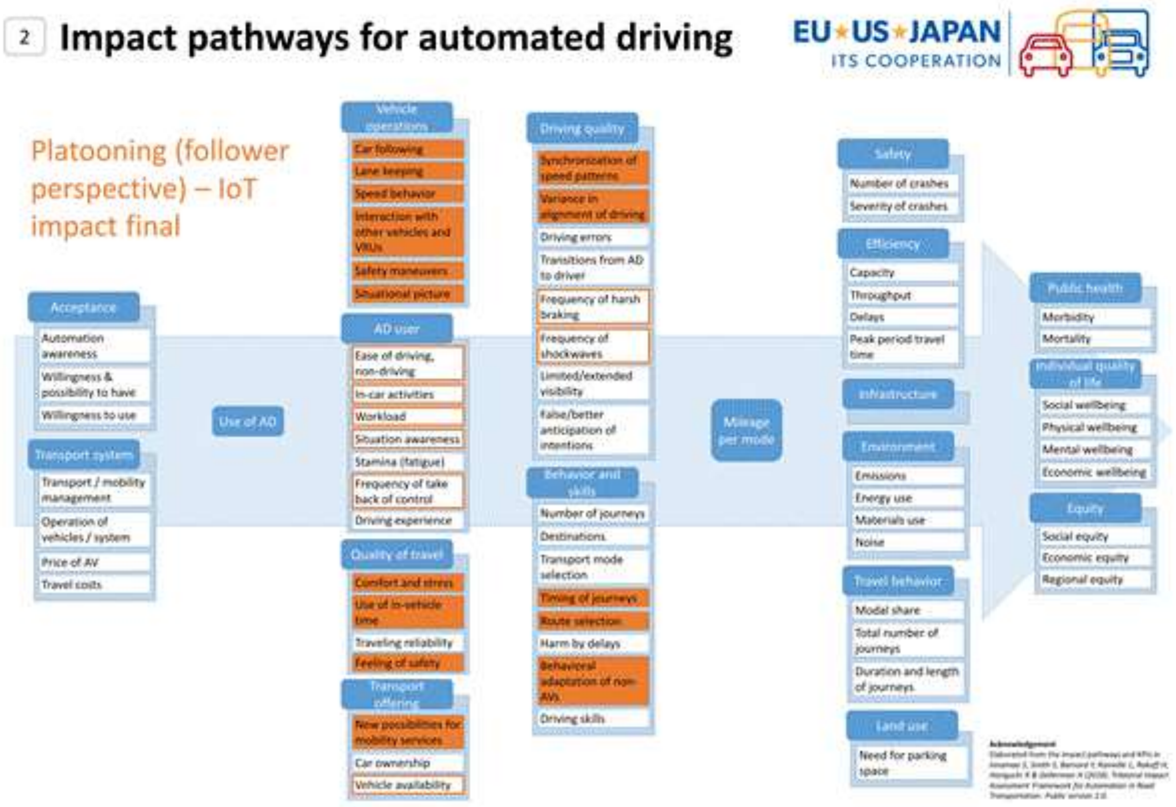


Figure 20 – Potential impact mechanisms of IoT for Platooning. (Orange coloured boxes indicate direct impacts, boxes with orange borders indicate more indirect or secondary impacts.)

Platooning differs from the other AD modes in the AUTOPILOT QoL evaluation in two ways. First, it is the only AD mode with potential use lasting for a substantial part of the driving both in time and space (in contrast to the UD and HP functions, which address very specific, time and space limited situations during the drive). Second, the AD mode is furthest apart from the defined baseline (SAE L4 highway pilot). The expected benefits of IoT for this AD mode are considered from a follower's perspective (not the platoon leader) and are described below.

Vehicle operations: Due to the wider scope of the platooning AD mode, covering longer stretches of driving, changes are expected to all areas (*Car following, Lane keeping, Speed behaviour, Interaction with other vehicles and VRUs, Safety manoeuvres, Situational picture).* Reliable connectivity between the platoon leader and following vehicles allows for keeping shorter headways, which allows for energy efficient driving of following vehicles and the most efficient use of road space. This optimisation is restricted by safety issues arising from reaction and braking distances. It is envisaged that with increased connectivity and data availability road and traffic conditions can be better anticipated and therefore, not only could the distance be reduced in certain circumstances, but also, could be more adaptable when new information is received. This could make the vehicle operation smoother and more efficient. Better anticipation of traffic situations due to information flow via IoT helps stabilise car following behaviour in general, keeping the headway to the vehicle in front as well as the AV's position within a lane more constant than without connectivity. The vehicles driving in a platoon use the same speed, therefore driving speeds are harmonised. Especially as the number of vehicles in a platoon increases, the platoon may cause a barrier to other vehicles, e.g. by hindering other vehicles from changing into the lane of the platoon. The situational picture of the vehicle is expected to improve with IoT connectivity; with a greater degree of connectivity a platooning vehicle would have access to much more data and information than the baseline L4 vehicle.

There is particular importance for a platooning group to have accurate awareness of the location and speed of other vehicles in order to judge how to maintain smooth journeys and constant speed, and when to perform safe overtaking manoeuvres of multiple connected vehicles. Additionally IoT connectivity of both V2V and V2X is expected to increase the accuracy of the situational picture, and the vehicle can therefore make more informed predictions of and interaction with surrounding vehicles. This is particularly important in high levels of mixed traffic when there are unconnected vehicles on the same road.

In emergency situations, it would be expected that highly connected automated vehicles, which have a highly grained situational picture (see later), would be better informed to make the most safe decisions compared to a L4 vehicle with limited connectivity and the potential to choose to return driving control to the user. However, the choice of manoeuvre would be restricted by the algorithms and programming of the vehicle computers.

AD User: Compared to the baseline of a motorway pilot, minor/indirect changes are expected from platooning on the *Ease of driving/non-driving, In-car activities, Workload, Situation awareness* and *Frequency of take back of control*.

During the platooning operation of a long distance journey, activities of users may only be limited by available space, journey duration, other vehicle occupants or personal preferences/restrictions (eg motion sickness). This would expect to be generally the same than for a L4 or non-connected vehicle. In-car activities may be affected for some users if motion sickness can be reduced with a more smooth driving behaviour due to the connectivity.

The workload of an AUTOPILOT platooning service user should be minimal during the platooning journey. However, if the user is unable to engage in a preferred activity for some reason, then they may experience boredom or fatigue.
a level of anxiety to increase workload due to the lack of control over the vehicle for some people.
The users' situation awareness may be decreased or increased, depending on how the HMI is implemented and to which degree information of the vehicle, platoon and traffic status is made available to the user.

Quality of travel: Changes are expected to *Comfort and stress, Use of in-vehicle time* as well as *Feeling of safety*.

Riding *comfort* is expected to be improved in connected automated vehicles compared to unconnected L4 vehicles due to better information on and anticipation of the current and upcoming events and conditions.

The design of and trust in the system is important in the reduction of stress - if successfully implemented in a fully automated and connected vehicle, the user of a following vehicle should expect a low degree of stress as there should be no responsibilities for vehicle operation during the journey. Furthermore, when using a platoon joining function, there can reduced anxiety concerning getting to the platoon at the right place and the right time. Stress may also be reduced compared to the baseline if the user can communicate directly with the platoon leader, and potentially also other platoon members (allowing a 'community' to be formed as they all share a journey). Platoon members could have access to monitoring the journey, viewing the same information as the leader (if they wish) regarding potential upcoming hazards, delays or route changes.

On the other hand, the removal of driving/operation responsibilities could lead to new sources of stress if the trust in the system is low and there is concern over lack of control, malfunction or actions of the leading driver. There could also be a negative impact on comfort as the feeling of 'driving pleasure' will be removed for some users and those who are not able to partake in activities possible within a vehicle that give them pleasure, leading to boredom. This may especially be a problem for those who suffer from motion sickness (Penttinen et al. 2019). This can sometimes by overcome by the action of driving, but be exasperated by carrying out other concentration activities. Although the ride should be smoother in a connected AV (which could reduce motion sickness), it is not clear how these would balance out. For some, the anxiety related to sharing a 'journey' with strangers (albeit in separate vehicles) may increase stress and discomfort, though the ability to connect with them in a connected vehicle could alleviate this to some degree.

The *use of in-vehicle* time may be affected for some users if motion sickness can be reduced with a more smooth driving behaviour due to the connectivity.

It is uncertain how IoT connections can benefit the use of time over and above a non-connected vehicle. Similar to comfort and stress, there are marginal benefits to be expected from a smoother ride than a vehicle using sensors alone, leading to a better degree of comfort and so the tasks can be enjoyed more fully or may be easier to engage in if concentration is needed, in-vehicle motion needs to be limited or motion sickness is reduced.

Some people may experience anxiety related to the lack of control over the vehicle, depending on the implemented HMI and the information and control options available to the users.

IoT connections could improve *feeling of safety* if additional information is available to the users. However, there is concern regarding the programming of AV algorithms and the impact of computer malfunction. Knowing a vehicle also relies on IoT is unlikely to increase confidence, rather give more reason for malfunction concern, especially in relation to computer 'hacking'. Thus, even if vehicles may be objectively 'safer', the users' perception of safety may be different. This could especially be the case for platooning as vehicles could be driving closer together and at faster speeds, and requires some degree of confidence in the leading driver. Furthermore, the degree of 'mixed' traffic on the roads could affect this feeling of safety. IoT could alleviate this concern if platoon users are able to communicate with each other.

Combining the observations above, fully automated and connected platooning opportunities would likely improve quality of travel in the context of personal mobility for the majority of people as opposed to driving a L4 unconnected vehicle. The driving behaviour could be smoother and journeys should be safer. This would improve comfort, reduce stress and allow a more productive or preferred use of in-vehicle time. This could allow individuals to participate in longer journeys in a platoon (and therefore more destinations) than the alternative. However, not all people may be able to partake in activities and some may feel obliged to work more. The greatest potential negative impact on personal mobility for the majority is that even if vehicles are safer, the 'feeling' or perception of safety may be reduced due to concerns of malfunction or hacking. Thus for those not comfortable with platooning their personal mobility may be disproportionally lower than the wider population.

Transport offering: Platooning may provide an opportunity for new *Mobility services*, as examined in the case of Platooning in Brainport. This may lead to changes in *Vehicle availability.*

IoT may open up new possibilities for mobility services which include a platooning option on motorway journeys. Once in the platoon there are potential harms for new mobility services if there is limited trust in other platoon users, especially the leader, however this may be reduced by connectivity between platoon members. Further negative impacts (relative to L4 unconnected) could

arise from malfunction or cyber security breaches (actual or perceived).
It is possible the IoT connections could improve rebalancing of shared vehicles, as there will be additional data available regarding the locations of vehicles and users at any point in time, and predictability of availability based on journey conditions.

The AUTOPILOT platooning AD mode could have a positive impact on transport offering in the context of personal mobility for the majority of people as opposed to driving a L4 unconnected vehicle. There may be greater confidence in when and where vehicles would be available. However, on the other hand, the service (if successful) could have a negative impact on wider (and more sustainable) mobility services, itself impacting on a wider population.

Driving quality: Due to its nature, platooning is expected to affect *Synchronisation of speed patterns* and *Variance in alignment of driving*. This may lead to changes in the *Frequency of harsh braking* and *Frequency of shockwaves.*

As discussed under vehicle operation, increased connectivity of vehicles is expected to lead to more harmonised driving behaviour in terms of speed, car following and lane keeping.

As a result of this, if there are many connected automated vehicles sharing the road (either within the platoon, forming other platoons or on solo journeys), the sharing of data and information between them, including on their destinations and occupants needs, could lead to a greater synchronisation of journeys, part of which may be the synchronisation of speed patterns. Further, it has been shown that Connected ACC is more effective than ACC (Ploeg et al. 2011). However, in situations where there are high levels of mixed automation in traffic, the degree of synchronicity that can be achieved is unclear.

When there are many fully connected and automated platoons within a traffic network, speed patterns may be better synchronised. This is because the situational awareness is higher due to the connectivity, allowing smaller headways, dampened speed variations (Ploeg et al. 2011) and more stable operations (Milanes et al. 2014).

The connected vehicles in platoons may adapt their alignment accordingly to avoid ruts forming. Furthermore, the vehicles within the platoon may communicate with each other directly to provide more accurate information on the positions (both relative to the road and each other) and adjust as needed.

Harsh baking occurs in situations when a speed reduction has not been anticipated. As anticipation of events is improved with connectivity, such events may be more easily predicted and reacted to. Rear-end collisions within vehicles in a platoon should be prevented. Furthermore, in a traffic system with many fully connected and automated platoons, traffic flow may be better predicted and there may be fewer shockwaves, both of which lead to harsh braking.

Shockwaves tend to be caused by mixed speed patterns and harsh braking (reference). As previously discussed, harsh braking can be reduced by high levels of connectivity, and speed patterns can be synchronised. As such, the occurrence of shockwaves may be reduced.

Behaviour and skills: The new services enabled by platooning via IoT may lead to changes through *Timing of journeys, Route selection* and *Behavioural adaptation of non-AVs.* Through behavioural adaptation, manual vehicle drivers may be encouraged to use smaller headways as well. Studies have shown that non-AVs tend to travel at smaller headways when travelling close to platoons, imitating the short headways of the automated vehicles (Gouy 2013; Gouy et al. 2014, Yang et al. 2019). A fully connected platoon could travel at shorter headways than L4 vehicles, while at the same time being more adaptive to surroundings and reactive to other driver behaviour.

Automated driving could increase travelling during peak hours (Rämä et al. 2018), which would probably apply to the platooning service as well. This is presumably because of the possibility for alternative use of time during a journey.

IoT enables better anticipation of traffic and road conditions ahead, which may cause the platoon to adjust routes based on the predicted road conditions for that particular platoon. In addition, the availability of platooning on motorways only may cause users to favour motorways over other routes, even if the journey is longer. The availability of real-time information could also allow users to make a more informed choice of route. The system itself could make different choices both before and during the platooning journey.

The use of IoT is expected to offer the user a more informed estimate of duration and optimum timing and thus could have an impact on travel choices. The biggest impact on timing would likely be whilst traffic contains a large mix in automation levels.

4.1.5.2 Implications for safety

Traffic safety is affected through the boxes Vehicle operations, AD user, Driving Quality and Behaviour and skills.

Direct impacts are expected from IoT on traffic safety through all mechanisms in *Vehicle operations*. If everything works correctly, safety impacts are mostly expected to be positive compared to the baseline (smoother following, lane keeping and speed behaviour; improved situational picture).

The improved situational picture due to connectivity allows for better anticipation of the traffic situation ahead and can therefore be considered as beneficial for safety.

It is expected that vehicle operations of vehicle with the AUTOPILOT platooning service could potentially increase traffic safety over a L4 counterpart. This conclusion is based on the assumption that the increased data and information received by the vehicle allows for a more highly grained situational picture on which to base its safety-related decisions.

It is possible that reduced situation awareness and engagement in other tasks could have a negative impact on safety in certain conditions, as the user would not be prepared to react to an emergency situation.

Impacts in the *AD user* field are expected to occur indirectly, and no direct safety impacts are expected. The effects are more related to user comfort and acceptance.

Driving quality is expected to lead to traffic safety impacts by Synchronisation of speed patterns and Variance in alignment of driving, as platooning vehicles drive with the same speed and aligned to each other, and this may also lead to carry-over effects to other (automated or manually driven) vehicles.

Traffic safety and efficiency are ultimately influenced by the driving quality of the overall traffic system. Driving quality is a product of the operations of individual vehicles within that system. When a system has numerous platooning journeys contained within it, their operation and driving quality can have a large impact on the overall system safety. However, interaction effects with non-connected and manual vehicles have to be considered.

Traffic safety likely to improve as speed differences between vehicles decrease. This also leads to less overtakings.
The smoother traffic patterns may lead to decrease in Frequency of harsh braking and shockwaves, which in turn may increase safety by reducing secondary accidents.

Regarding Behaviour and skills, the Timing of journeys as well as Route selection have impact on safety due to changes in exposure and different accident risk on different route types and traffic conditions. The direction of impacts (positive or negative) depends on the effect of these changes. In addition, Behavioural adaptation of non-AVs can lead to decrease in safety due to closer following of vehicles, even if not in a platoon (imitation effect), and/or increase in safety due to imitation of a smoother driving style with lower or more constant speeds and less overtaking.

A fully automated and connected vehicle in a platoon may have some limited safety advantage over L4 vehicle because of its higher degree of situational awareness and better anticipation. Behavioural adaptation of manual drivers imitating the short headways of platooning vehicles could lead to a higher risk of accidents for non-AVs.

Further, when an AV goes into manual mode after a period of driving in automated mode, drivers may tend to maintain shorter headways (Skottke et al. 2014), which could happen when an AUTOPILOT platoon disconnects. Behavioural adaptation of AUTOPILOT platooning users after the automated platoon ends may lead to an increase in accident risk.

Behaviour and skills of both AV and non-AV drivers are affected by the presence of platooning on highways, which may lead to increased safety risks. It is not clear if the fully automated and connected platoon would increase or decrease this risk for all road users. Their higher degree of anticipation may lead them to operate in a manner that may be unsafe were they non-connected and/or non-automated. As this behaviour could be adopted by other road users, there is a responsibility to adapt to road conditions, and 'lead by example', which could lead from a situation of decreased relative safety to one which could be safer.

4.1.5.3 Implications for Efficiency and Environment

Changes to traffic efficiency with the Platooning AD mode are expected through the areas *Vehicle operations, Driving quality* and *Behaviour and skills.* In *Vehicle* operations, smaller gaps between vehicles and more constant speed behaviour lead to an increase in efficiency. Less acceleration leads to decrease in emissions.

It is recognised that shorter headways between vehicles can lead to more energy efficient driving (due to aerodynamic drag). Although this impact could be small for automobiles (which are likely to be relatively energy efficient as the powertrain technology would likely be also advanced), this efficiency could make an impact over long distance journeys that would likely occur in a platoon.

The changes in interaction with other vehicles may have positive or negative implications for traffic efficiency and the environment. On the one hand, the interaction between the vehicles driving in the platoon is expected to be beneficial due to better coordination of the movements, but the interaction with vehicles that are not connected may have negative impacts. For example a platoon with several vehicles driving with close distances may hinder drivers of manual vehicles, or non-connected AV, to make necessary lane changes. This may lead to disturbances in traffic flow.

The higher level of situational awareness means that the speed behaviour of a platoon can be smoother than a non-connected platoon, which is a more energy efficient way of driving. However, it is not clear how much of an overall impact this could be over a non-connected platoon. One specific advantage could be the adaptation of speeds in areas with environmental monitoring, requiring reduced speeds when pollution thresholds have been exceeded. Although this technique is already employed on some smart motorways by variable speed limits, a connected vehicle could have a more nuanced picture of the situation and adapt itself. However, should the platooning vehicles have zero tailpipe emissions there is no advantage, and it is also not clear how much more of an impact this would be in a platoon than in a solo vehicle.

Vehicle operations of AUTOPILOT vehicles within a platoon can be smoother and more efficient compared to non-connected L4 vehicles due to their better anticipation. However, it is not certain how large this impact could be (especially for zero tail-pipe emission vehicles), and may only be marginal and/or apply to very long journeys.

Regarding *Driving quality*, direct impacts of platooning to traffic efficiency are expected from synchronisation of speed patterns and less variance in the alignment of driving. These impacts are likely to be positive but small. Indirectly, efficiency and environment are affected due to less harsh braking and less frequent shockwaves.

Better synchronised vehicle operations could lead to improved network efficiency and capacity, with less shockwaves. Harsh braking and acceleration are energy inefficient ways of driving, smaller headways improve aerodynamics which contribute to energy efficiency, thus all have local and global pollution impact. Improved network capacity means more vehicles driving on the network, which is likely to have negative environmental impacts (eg pollution, noise). On the other hand, if road networks are better used then additional road links may not be required to align traffic supply and demand.

As mentioned previously, the improved anticipation of a fully connected and automated platoon would be expected to reduce harsh braking situations, making driving smoother and more synchronised. This has a positive impact on the energy efficiency of a powertrain so can have both local and global pollution impacts. Therefore, also related shockwaves could be reduced.

The existence of fully connected and automated vehicles within a platoon rather than L4 unconnected platooning vehicles is anticipated to improve driving quality across the network. Improved driving quality across a traffic network means more efficient driving across it, with a lower environmental impact.

On *Behaviour and skills*, traffic efficiency is affected by different *timing in journeys* and *route selection* – impacts of both are expected to be positive for traffic efficiency if they lead to a more even spread in travel demand over space and time. Regarding environmental impacts, different route selection may have unwanted impacts on local emissions in certain areas. *Behavioural adaptation of non-AVs* may have positive or negative implications.

There may be more driving during peak hours with fully automated and connected vehicles in a platoon (Rämä et al. 2018), presumably as users are able to use their time productively. If this lead to congested networks all vehicles on the network may not be driving as efficiently as they otherwise could, increasing emissions.

The improved situational awareness of a fully and connected autonomous platoon may lead it to choose different routes than the L4 baseline vehicles. These could ideally be based on more efficient or less polluting routes within the network. In addition, the availability of platooning on motorways only may cause users to favour motorways over other routes, even if the journey is longer.

Non-AVs may adapt their speed and headway to that of platoons they travel close to (Gouy 2013; Gouy et al. 2014, Yang et al. 2019). Despite the safety concerns of this previously discussed, if the platoon is driving in an efficient way, other road users could be encouraged to drive more efficiently, reducing the environmental impact across the network. There may be limited impact of the fully automated and connected platoon over a group of non-connected L4 vehicles, other than its better situational picture and anticipation leading to the most efficient speed (the difference of which is unknown).

The behaviour and skills of non-AV drivers and AV users may be marginally altered by the presence of platooning automated vehicles on the motorway network, with connected vehicles having a slight advantage over less connected vehicles. The driving quality across the network may be improved leading to more efficient driving and less related pollution.

In addition to these mechanisms described, indirect benefits to efficiency and environment can be expected if traffic safety is improved and there are less accidents, which often lead to congestion.

4.1.5.4 Implications for Personal mobility

Personal mobility is affected through *Quality of travel, Transport offering* and *Behaviour and skills.* Compared to the baseline of Level 4 Highway pilot, user *comfort* is expected to increase due to a smoother ride enabled by the anticipative information through IoT. This may also positively affect driver *stress.* On the other hand, new sources of stress can arise in the platooning experience, e.g. related to the coupling of the vehicles. Depending on the information given to the user, the *feeling of safety* may also be affected.

Platooning with IoT has potential to lead to new mobility services being created (as for example the “platooning date” tested in Brainport). From a personal mobility perspective, new mobility choices can be considered positive.

On a wider scale, if users of new mobility services prefer individual travel the platooning option could be chosen over other more sustainable mass transit options for the same journey. If this occurs on a large scale, these alternatives may not be economically viable, highway systems could be over-utilised and the personal car would remain centric within transport systems.

Changes in *timing of trips* and *route choice* are also possible, and their impacts for personal mobility are considered positive.

4.1.5.5 Summary for Platooning

Figure 21 shows the expected benefits of IoT and implications for traffic safety, efficiency and environment and personal mobility for the AD mode Platooning.

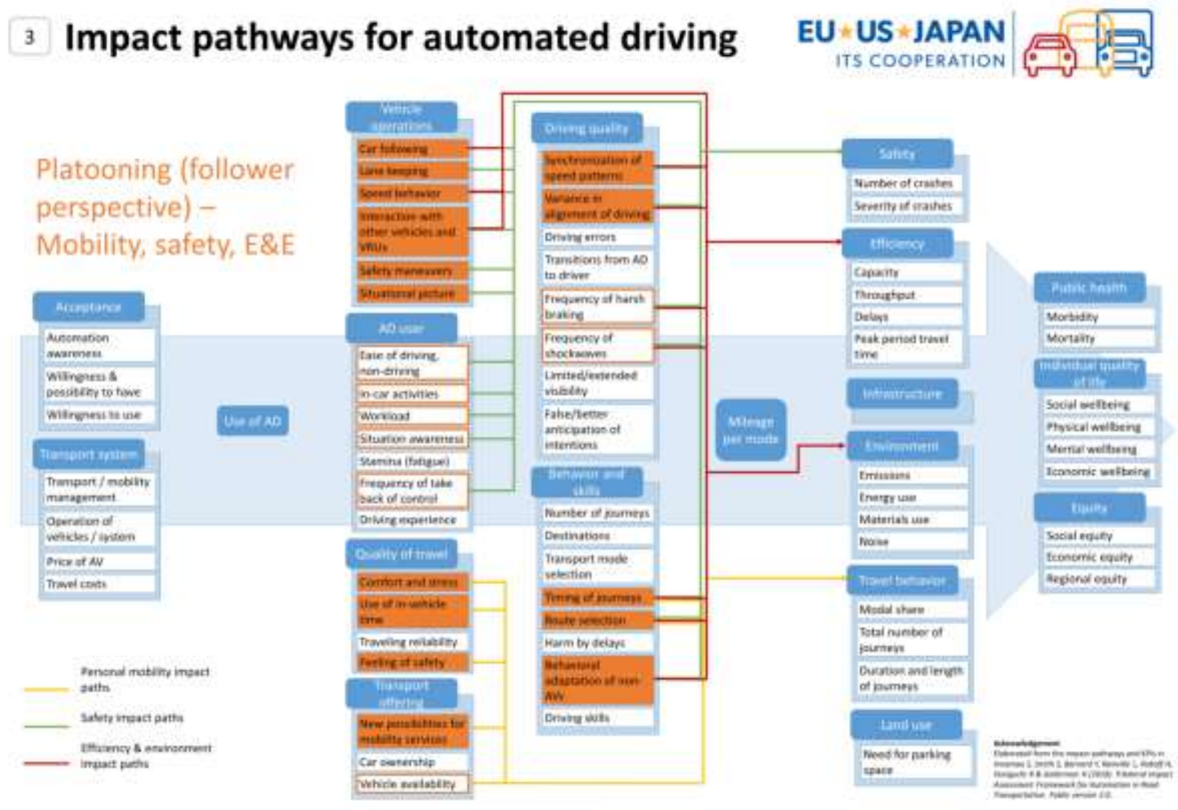


Figure 21 – Expected benefits of IoT and implications for traffic safety, efficiency and environment and personal mobility for the AD mode Platooning.

4.1.6 Summary of findings

4.1.6.1 Summary of IoT impact mechanisms

A summary of the areas where changes are expected due to IoT (compared to the baseline of non-connected automated driving) is shown in Table 4 below. Most impacts of IoT were assumed to emerge through the mechanism areas Vehicle operations and Quality of travel. Vehicle operations largely relates to the driving behaviour of vehicles, which can be enhanced with anticipation provided by IoT connectivity. The vehicle is able to adjust to upcoming situations earlier and more smoothly. Quality of travel largely consists of users' subjective perception of the trip, which can improve with the IoT connectivity e.g. by enabling more comfortable rides and better traveling reliability compared to non-connected autonomous driving. Per AD mode, most impacted mechanisms are expected for Platooning.

Table 4 – Expected mechanisms where IoT has an effect compared to the baseline. Darker colour signals direct effects, light colour indirect effects.

	AVP	UD - SI	UD - VRU	HP - HD	PL
Vehicle operations					
car following					
lane keeping					
speed behaviour					
interaction with other vehicles and VRUs					
safety manoeuvres					
situational picture					
AD User					
ease of driving/non-driving					
in-car activities					
workload					
situation awareness					
stamina (fatigue)					
frequency of take back of control					
driving experience					
Quality of travel					
comfort and stress					
use of in-vehicle time					
traveling reliability					
feeling of safety					
Transport offering					
new possibilities for mobility services					
car ownership					
vehicle availability					
Driving quality					
synchronisation of speed patterns					
variance in alignment of driving					
driving errors					
transitions from AD to driver					
frequency of harsh braking					
frequency of shockwaves					
limited/extended visibility					
false/better anticipation of intentions					
Behaviour and skills					
number of journeys					
destinations					
transport mode selection					
timing of journeys					
route selection					
harm by delays					
behavioural adaptation of non-AVs					
driving skills					

4.1.6.2 Summary per impact area and AD mode

The impacts of IoT and AD on traffic safety and efficiency and the environment are assumed to be rather small for the urban driving and hazard warning AD modes, due to their limited scope. Depending on the level of technology, implementation and human behaviour, the impacts can be positive or negative. However, this may change if with a rising penetration rate there is more congestion and the personal mobility options are in effect reduced. Changes in personal mobility behaviour have potentially large impacts also on traffic safety and efficiency and environment, as they define the amount of travel and the modal split. These are main factors defining the impacts on safety, efficiency and the environment.

Due to the scope of the AD modes AVP and Platooning, the potential impacts of those are further-reaching. Both can have significant impacts on travel behaviour and change people's travel patterns. Depending on their direction, these potential changes in travel patterns are reflected by positive or negative impacts on traffic safety and efficiency and the environment.

Having fully connected and automated vehicles forming platoons within the road network seems likely to have a positive impact on the overall network efficiency and this on the surrounding environment. The impact is derived from the better situational awareness allowing a smoother and more anticipatory style of vehicle operations due to the high connectivity, and the influence that their presence may have on other vehicles within the network. However, significant impacts on efficiency and environment may only be witnessed when there are high levels of connectivity and automation across the whole traffic network.

Services like AVP have potential to increase car ownership due to the time-saving and stress-reducing benefits compared to conventional or non-connected autonomous parking. AVP could also improve vehicle availability of shared vehicles if parking areas are conveniently located.

The Hazard warning service was the only service where overall impacts can be expected to be positive (though small). AVP is expected to have overall benefits for safety and mobility, but the overall impacts for efficiency and environment are not clear.

As stated before, the AD modes AVP and Platooning are expected to have the largest impact potential due to their potentially large impact on the trip as a whole. Therefore, indirect impacts for safety and efficiency and environment can be significant, as the impact potential increases with increased number and/or duration of trips using the AD modes.

The greatest safety potential of the AUTOPILOT AD modes over the baseline non-connected autonomous vehicles is probably the more highly grained situational awareness and enabled better anticipation of events and conditions ahead. Negative impacts on traffic safety could arise from behavioural adaptation as well as from changes to exposure. No AD mode is expected to have only negative impacts.

As personal mobility is regarded to improve with the availability of more mobility options, the AUTOPILOT AD modes are expected to be positive for personal mobility.

4.1.6.3 Summary for impact mechanisms for Mileage per mode (Block 2)

<u>Vehicle operations</u>

Vehicle operations considers the immediate driving behaviour of the vehicle, such as its speed, headway to the car in front, and interaction with other road users.

Speed behaviour is assumed to change in automated driving with IoT compared to without connectivity. Due to the connectivity enabling better anticipation, speeds are assumed to be more moderate and adjusted earlier to upcoming situations. In environments with VRU, such as the Urban driving functions, this can be considered positive for traffic safety. With high penetration rates, the overall traffic can be harmonised, leading to more efficient traffic flow. A lower number of starts and stops translates to less emissions of internal combustion engine vehicles.

Early detection and manoeuvring along with harmonised speed profiles are expected to improve the interaction process between AV and other road users by enabling a safer and lower risk interaction. Minimising accidents and near misses enhances the efficiency of the traffic system as well leads to less emissions.

Improvements in speed profiles, harmonised arrival and braking distances, removal of unnecessary stops, braking, manoeuvres and interactions are expected to lead to an improved traffic network with increased efficiency. However, these enhancements are applicable to certain scenarios and not on the whole road network.

Interaction with manually driven vehicles can have negative effects, if drivers of manual vehicles are frustrated by CAV adhering to speed limits, for example. This may lead to an increase in overtakings and associated accelerations and decelerations, which are detrimental to traffic flow and may increase risky situations (Rämä et al. 2018).

Regarding the different AD modes, Vehicle operations are expected to mostly have safety benefits for Hazard warning and Platooning, while the direction of impacts on safety is unclear for the other AD modes. For efficiency and environment, impacts are unclear for all AD modes, largely due to uncertainties in interaction with other road users (AVP, Signalised intersection, VRU detection, Platooning) and speed behaviour (Signalised intersection, VRU detection).

AD User

The impact mechanisms of the AD user category relate to the behaviour, awareness and experience of the AD user. The impacts are relevant for traffic safety and considered generally positive but small. In fact, they can be considered more related to user comfort.

Quality of travel

The Quality of travel category is related to how the user perceives the use of the AV: how comfortable or stressful the ride is, how in-vehicle time is used, what the reliability of travel is as well as the feeling of safety.

Comfort is dependent on vehicle design, but it has been generally found that AD improves comfort (Gerla et al. 2014, Kolarova et al. 2019, Lemmer, 2019, Pakusch et al. 2018) and reduces stress (Daschkovska et al. Kolarova et al. 2019; Singleton, 2017, Singleton, 2019). This may be particularly relevant to fully automated platooning which will likely occur during longer journeys where comfort is more important. Also AVP is expected to greatly increase comfort and convenience of car use.

The ride itself would be expected to be smoother in connected automated vehicles, which should have better knowledge of their surroundings and upcoming route hazards. Early detection of events is expected to increase the comfort and reduce the stress of the user, which will impact the quality

of their travel.
However, the design of and trust in the system are important in the reduction of stress.

On the other hand, IoT with AD could lead to different form of stress if the trust in the system is low and there is concern over lack of control, cybersecurity, malfunction or actions of leading driver. For some, the anxiety related to sharing a 'journey' with strangers (albeit in separate vehicles) may increase stress, though the ability to connect with them in a connected vehicle could alleviate this to some degree.

Rämä et al. (2018) estimated that travelling reliability can be increased with new automated vehicle services, but on the other hand it can be decreased if private car use (and thus congestion) increases. Connectivity with IoT could mitigate this to some extent, but not completely.

Quality of travel is related to personal mobility impacts, and generally thought to improve mobility with all AD modes.

Transport offering

The category transport offering refers to the potential changes in mobility options available to users. Transport offering is related to personal mobility impacts for the AD modes AVP and Platooning, and impacts on mobility are expected to be positive.

Driving quality

Driving quality is related to the changes in driving behaviour on a vehicle level (*Vehicle operations)* and how well it is able to drive but also on traffic flow level and how smooth the traffic flow is. Driving quality concerns the translation of impacts on single vehicle operations to the road network in a wider scope.

AUTOPILOT AD modes have potential to lower errors regarding the detection of and interaction with VRUs, leading to safer experience of these interactions. IoT is expected to extended visibility in anticipation of the VRU, leading to earlier braking. Less errors lead to less unnecessary manoeuvres and less accidents on route, therefore a positive impact to traffic efficiency and environment. Harsh braking is expected to decrease, as the optimal reactions will occur between the vehicle and the VRU. Redundant braking can be reduced.

All piloted AD modes are assessed to have positive impacts on driving quality regarding traffic safety and efficiency and the environment.

Behaviour and skills

The topic 'behaviour and skills' is largely related to the personal mobility behaviour of individual users (and non-users) and the skills required.

This category of impact mechanisms has a potentially large impact on quality of life, as it includes mechanisms dealing with the change in travel behaviour (e.g. number of trips, mode choice, route choice). Therefore, the overall impacts on traffic safety, efficiency and the environment are largely dependent on the changes in these mechanisms with AD and IoT.

The successful implementation of the AD modes can potentially affect route selection, with users not avoiding urban and complex driving contexts, conditions and arrangements. For example, an older driver will not select a busy, life-boasting city centre at night, where potentially pedestrians would cross the road, without hesitation and respect for signalized sections. However, when re-routing is done by the AV, then the user will not choose the route, but the system will do so to avoid a risky or congested situation with other road users. The complexity and the length of routes might increase, as the detection system will 'unload' the user, but the expected impact will not be decisive or very important for personal mobility.

Users will choose any route with no hindrances or second thoughts, regardless if they are near or far because of the AV and will not avoid complex and tiring traffic conditions (e.g. congestion, shopping centre areas with many pedestrians around, urban centres, etc.) which will potentially negatively affect the traffic flow and density and similarly the environment, because of increase in noise, emissions and fuel consumption. It is still uncertain if the increase in duration and length of routes will be counterbalanced by the optimisation and harmonisation of traffic and increase of AV and shared transportation options.

Over time, when drivers get used to high level automation support, their driving skills may deteriorate (e.g. Rämä and Koskinen 2019). Added upon the existing deterioration, not relying on their own senses to detect other road users, and especially road users, will potentially lead the other users to be left out from the attention of the driver as well as the usual allocation of cognitive load for scanning the surrounding and anticipating movements and responses. However, AD modes with IoT can lead to establishing communication between various road users and not only vehicles, which will potentially lead to simple transfer of load and attention from one to the other task (driver/passenger).

Skills related to scanning the environment and interacting with other road users as part of the daily driving task may deteriorate. However, this will happen less because of IoT system and more of the AV use in general. If cooperation and interaction is supported and implemented, it could enhance the communication between users and, thus, create new skills and behaviours that would replace the traditional driving task-related ones. Deterioration of driving skills can decrease safety in manual driving situations.

The impacts of behaviour and skills on personal mobility are considered positive, as more flexibility in travel and increased mobility options improve personal mobility in general. The impacts on safety, efficiency and environment are less clear as they depend on the extent and direction of the changes to travel behaviour. The total traffic exposure may increase or decrease. Different travel modes have different accident risks and different emissions, as well as different impacts on the road network efficiency. Different road environments have different accident risks. The extent and direction of behavioural adaptation of non-AVs (such as manual vehicle drivers and VRU) is also largely unknown and can have positive or negative impacts on safety, efficiency and the environment.

Overall

Table 5 shows a summary of findings for *Block 2 – Mileage per mode* for each AD mode and impact area.

Table 5 – Summary of results. "+" indicates mostly positive impact, "-" indicates mostly negative impact. More indirect impacts in parentheses.

	Automated valet parking			UD - Signalised intersection			UD - VRU detection			HP - Hazard warning			Platooning		
	Safety	Eff.&Env.	Mobility	Safety	Eff.&Env.	Mobility	Safety	Eff.&Env.	Mobility	Safety	Eff.&Env.	Mobility	Safety	Eff.&Env.	Mobility
Vehicle operations	(+)	(+/-		+/-	+/-		+	(+/-		+	(+)		+	+/-	
car following													+	+	
lane keeping										+			(+)		
speed behaviour				+/-	+/-		+	+/-		+	(+)		+	+	
interaction with other vehicles and VRUs	+/-	+/-		+/-	(+/-)		+	+/-					+	+/-	
safety manoeuvres										(+)					
situational picture	+			+			+			+					
AD User	(+)			(+)			(+/-			(+)			(+)		
ease of driving/non-driving	+			+									(+)		
in-car activities				(-)			(-)			(-)			(-)		
workload	+			+									(+)		
situation awareness				+			+			+			(+)		
stamina (fatigue)															
frequency of take back of control				+									(+)		
driving experience	-						-								
Quality of travel			+			+			+			+			+
comfort and stress			+			+			+			+			+
use of in-vehicle time						(+)									(+)
traveling reliability			+						+/-						
feeling of safety			+			+			+			+			+
Transport offering			+												+
new possibilities for mobility services			+												+
car ownership															
vehicle availability			+												+
Driving quality	+	(+)		+	(+)		+	(+)		+	(+)		+	(+)	
synchronisation of speed patterns				(+/-)	(+)					(+)	+		+	+	
variance in alignment of driving													+	+	
driving errors	(+)			+			+			+					
transitions from AD to driver															
frequency of harsh braking				+	(+)		+	(+)		+	(+)		+	+	
frequency of shockwaves				(+)	(+)					(+)	(+)		+	+	
limited/extended visibility	+	(+)		+			+	(+)		+					
false/better anticipation of intentions				+						(+)					
Behaviour and skills	+/-	+/-	+	+/-	+/-		+/-	+/-	+				+/-	+/-	+
number of journeys	(+/-)	(+/-)	+												
destinations	(+/-)	(+/-)	+												
transport mode selection	(+/-)	(+/-)	+												
timing of journeys	(+/-)	(+/-)	+										+/-	+/-	+
route selection	(+/-)	(+/-)	+				+/-	+/-	+				+/-	+/-	+
harm by delays															
behavioural adaptation of non-AVs				-/+	+/-		+/-	+/-					+/-	+/-	
driving skills	-						-								

4.2 System dynamics modelling

4.2.1 Background and approach

In order to gain a better understanding of the potential QoL impacts in the future and to study the interactions between different factors, system dynamic modelling was applied. This chapter is based on work presented by Harrison et al. (2019).

The approach was developed on a base model of the transition towards car-sharing and highly automated vehicles (HAV) in the Netherlands (Nieuwenhuijsen et al. 2018).

This model was adapted and extended in order to understand the complexities of the attributes in relation to societal QoL and to explore the sensitivities to uptake of highly automated vehicles. Scenarios based on expert opinion and sensitivity testing allowed to examine the potential impacts on both CAV uptake and QoL indicators.

System dynamics (SD) modelling captures the behaviour of complex systems over time, combining product diffusion, non-linear dynamics, time-lags and feedback loops (Sterman, 2000). It has been widely applied across many sectors, including business, industry and healthcare, as well as increasingly within transport research (Shepherd, 2014). SD can be thought of as a two-step process:

- An initial development of a qualitative causal loop diagram, to establish the boundary, capture the key endogenous and exogenous variables and their connections that are key to a system of interest. This should lead to closed feedback loops within the system that can either be reinforcing (positive –an increase in one value leads to an increase of another) or balancing (negative – an increase in one variable leads to a decrease in the other).
- Quantification of the causal loop diagram through identifying the system-driving stocks (accumulations) and flows (rates), underlying equations to represent relationships and data inputs, then calibration to validate the behaviour.

SD modelling has been applied to the automobile industry and uptake of new vehicle technologies. Many of these studies have focused on alternative fuels and powertrain transitions. Other SD models that were developed to understand the uptake of advanced vehicle technologies include in-car navigation (Kim 2007), car-sharing services (Geum et al. 2014) and IoT impact on intelligent transportation (Marshall 2015).

There have been to date a limited number of studies which have used SD to study the uptake or impact of automated vehicles. Stanford (2015) studied the potential impact on total vehicle distance travelled through a successful introduction of AV, examining key variables and relationships within a broad system. He concluded that unstable responses leading to either automobile or public transit dominance are more likely than a steady, moderate transition towards an even modal split. This work was limited to a series of qualitative causal loop diagrams to explore the author's assumptions. The same author was involved in a study similarly focused on the impact on vehicle use and modal shift (Gruel and Stanford 2015), and again exploring causal loop diagrams of transport systems. Their findings were positive across all their scenarios (safer, better use of time, increased accessibility, lower monetary costs and less energy use). A key insight was that AVs alone are unlikely to lead to a sustainable transport system, so early policy intervention to avoid AV dominance is necessary. Nieuwenhuijsen et al. (2018) developed a full SD model to represent the diffusion of all AV levels, driven by technology development and also incorporating the uptake in car-sharing. Through three scenarios (Base, Conservative Bloom and Progressive Bloom) applied to the Netherlands, they concluded that there were high levels of uncertainty, though higher levels of automation are unlikely to gain large market shares (even long-term) without optimistic conditions (mainly related to economics and user perceptions). Using the results from Niewenhuijsen and an established SD-related model 'ScenarioExplorer' (Malone et al. 2001), Puylaert et al. (2018) considered the impacts and uncertainties of low levels of automation (L1-L3). They found that traffic and congestion would likely increase, though when cars are also connected there is less congestion despite a higher number of trips. SD modelling has also been applied to understand potential effects of AVs on land use and the transport system (May et al. 2019). In line with findings in other studies, the authors conclude that under all scenarios tested, total vehicle distance travelled would be expected to rise as AVs were introduced (with contribution from 'empty' trips), and this could lead to reduced public and active transport use, and suggest this could be mitigated by encouraging the adoption of shared vehicles. It is interesting that although these examples are few, there are similar conclusions drawn regarding both the uncertainty and the risk of increased vehicle use as AVs are introduced and become widespread, which is in conflict with aspirations of sustainable transport systems.

In the system dynamic modeling within AUTOPILOT the model developed by Nieuwenhuijsen et al. (2018) was used as a base and adapted to address the research objectives:

- What are the sensitivities of uptake to utility for highly automated CAVs?
- How do the AD modes developed in AUTOPILOT accelerate, enable or enhance CAV uptake?
- How does CAV uptake impact on QoL?

The SD model study considered the AUTOPILOT AD modes in a wider scope as part of shared mobility.
In the base model, private car ownership is gradually replaced by car-sharing, technological development is driven by research funding and learning, and adoption of technologies is based on vehicle attributes of price, comfort, familiarity and safety. A high-level overview of the key variables and feedbacks is shown in Figure 22, and full model details, including key equations and inputs are available in Nieuwenhuijsen et al. (2018).

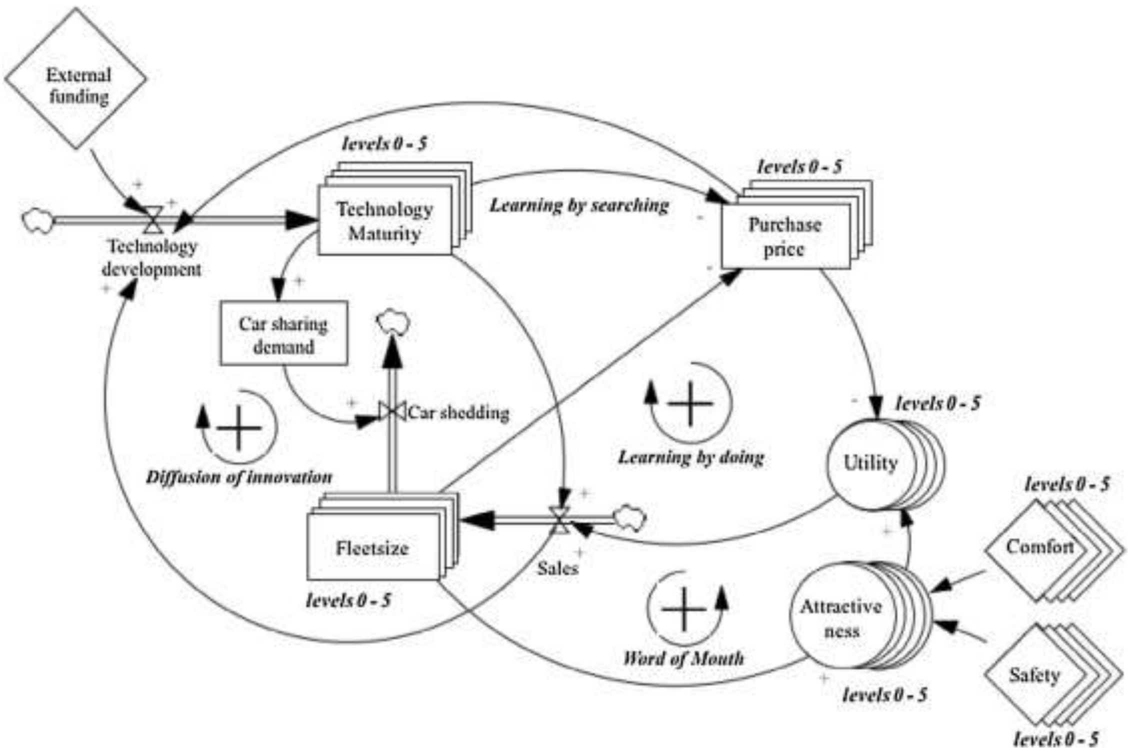


Figure 22 – High level overview of the base model (reproduced from Nieuwenhuijsen et al. 2018).

The base model (by Nieuwenhuijsen et al. 2018) was developed to operate under three scenarios: a Base scenario designed to reflect a "business as usual" situation (i.e. no major support for CAV) with a base year of 2000, and two optimistic "In Bloom" scenarios (one conservative and one progressive) starting from the year 2015, where conditions are favourable towards AV. In the AUTOPILOT work, the "In Bloom" Conservative Scenario was used as the base scenario. By adopting the In Bloom Conservative we are implicitly assuming that favourable conditions (economic and political) are in place. The model was run for 50 years until 2050. Modelling of fleet shares of different automation levels showed that L0 vehicles remain dominant in the early years and do not become insignificant until the 2040s. Highly automated driving (L4 and L5) become more dominant only after 2045 (accounting for around half of the fleet).

The sensitivity of fleet shares to variables related to utility and car-sharing was tested, as these could potentially be impacted by the AUTOPILOT AD modes. The transition of a user from using a vehicle of one level of automation to another level is driven (in part) by the relative utility of the two levels of automation. Utility was determined by the components Attractiveness (including Familiarity, Safety and Comfort) and Price. The Comfort and Safety attributes are assumed to be influenced by the availability of Autopilot use case technologies, which in turn depend on the availability and quality of IoT platforms.

Sensitivity testing showed that the uptake of highly automated CAVs is most sensitive to the attractiveness weighting in the utility and the level of Safety and Comfort. To explore the how the AUTOPILOT Services may accelerate, enhance or enable (C)AVs, we extended the model to include the uptake of these.

The three services considered in this model have been developed within the AUTOPILOT project and been subject to public user testing in Brainport, Netherlands. They are:

- Urban Driving: A service which connects to devices in an urban environment (e.g. traffic systems, pedestrian smartphones) so that the vehicle can take appropriate actions (e.g. yield to pedestrians).
- Highway Pilot: A service which alerts the vehicle of upcoming hazards (e.g. potholes, obstructions) on the motorway (detected by other vehicles) so the vehicle can take corrective actions.
- Platooning: A service which matches users wishing to platoon (drive in conveys with small headway and driven by lead vehicle) on long journeys.

The model extension is shown in Figure 23. *Fleet Size* (by automation level) is calculated within the base model, and the *Utility Modifier* is the key output of the extension which feeds back into the Utility function within the base model (thus leading to transfer between automation levels as described in the previous section). It is assumed that although all highly automated vehicles can be equipped with the services, they do not come as standard and a user would choose to use it at extra cost. However, the costs are not directly included in the model, as this data is not available. Scenarios can be run within the model by selecting which services (AD modes) are available as a separate service, with the base scenario having the assumption that all services are included as standard. Thus, with this model extension the potential impact of AUTOPILOT services was assessed.

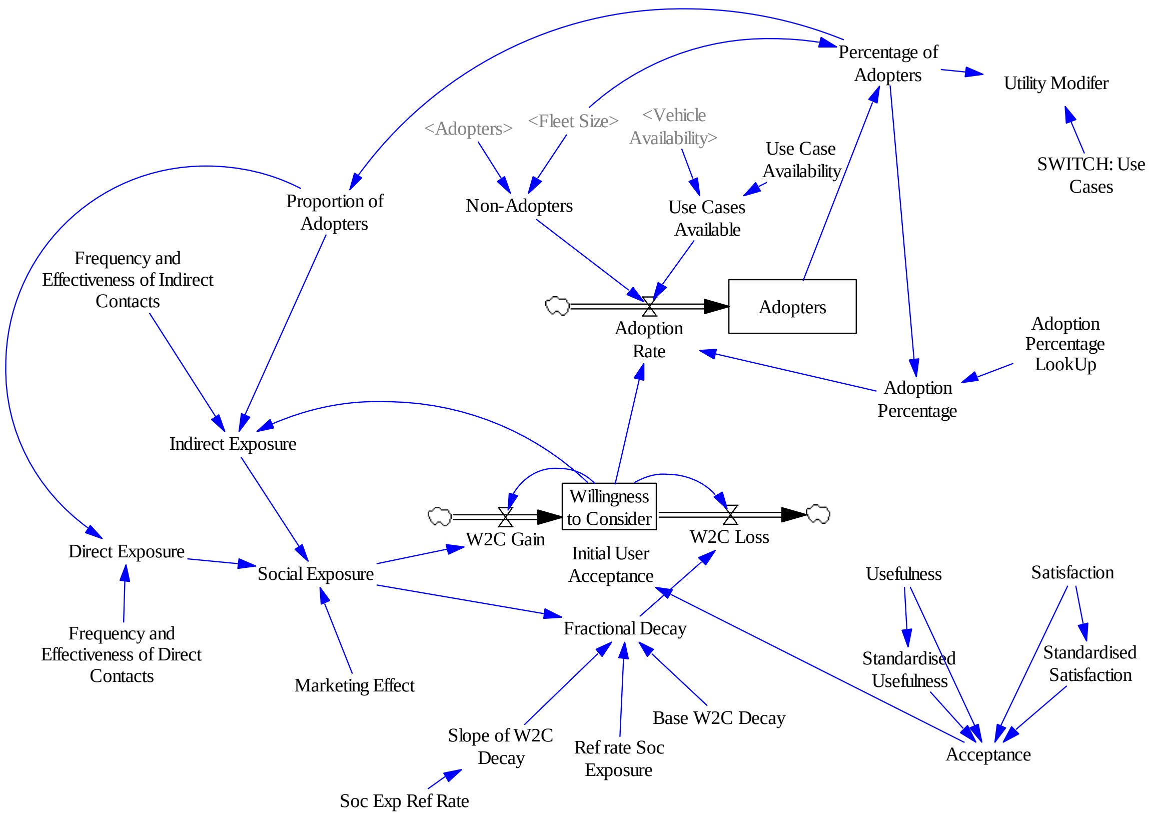


Figure 23 – Model extension (key concepts based on Struben and Sterman, 2008).

4.2.2 Results

The adoption rate of the services is a product of the number of non-adopters (within the highly automated vehicle fleet), the 'willingness to consider' the services, and the percentage of those who will use the service once adopted:

- *Number of non-adopters* is based on the fleet size of highly automated vehicles that are not already adopted. It should be noted that this considers vehicles, not users, due to structural restrictions of the base model.
- *Willingness to consider* reflects the appearance of the service within a decision set. This can increase over time when influenced by social and media exposure to the service, but can also decay if the exposure is low. The key inputs and structure are based on the willingness to consider electric vehicles (Struben and Sterman, 2008). The initial user acceptance has been determined using van der Laan scale of technology acceptance (Van der Laan et al. 1997), which determines 'usefulness' and 'satisfaction' from survey data of the three services in public user testing carried out in early 2019 in Brainport, Netherlands. The values of initial user acceptance determined here are:
    - Urban Driving: 0.7
    - Highway Pilot: 0.2
    - Platooning: 0.3
- The *percentage of adopters* are those who will use the service once they have adopted it. It has also been determined from the public user test surveys. Users were asked how often they used related existing technology (e.g. navigation systems, cruise control), and this data was used to create a look-up table that related the use of technology (at least once a month) to the population with access to the technology.

The proportion of users of each AUTOPILOT service is used as a utility modifier. The base model is set up in such a way that the comfort and safety levels are considered to be the maximum value assuming that the vehicle is fully connected and automated. This would only be the case when the full potential of CAVs is met, i.e. when all services are adopted. Although it is recognised that there are other services that may contribute, our interest is focused on the particular services developed within AUTOPILOT. It is further assumed that the three services considered contribute equally to the utility. Thus, the *attractiveness weight* is assumed to have a minimum value of 0.5 and a maximum value of 0.8, where each service can contribute up to 0.1. For the *comfort and safety levels*, there is an assumed minimum equal to the Level 3 values (Safety = 0.3, Comfort = 0.5), and the maximum is the base value for Levels 4 (Safety = 0.7, Comfort =0.8) and Level 5 (Safety = 1, Comfort = 1). Each service contributes up to one third of the difference between them.

Results in Figure 24 show the uptake of the three AUTOPILOT services by HAV users (under base conditions). The speed of uptake is affected by the initial user acceptance and the knock on effect that this may have on social exposure. It can be seen that the variance between the service adoption only holds for around 20 years (at around 80% of adoption), and no services are fully adopted by 2050.

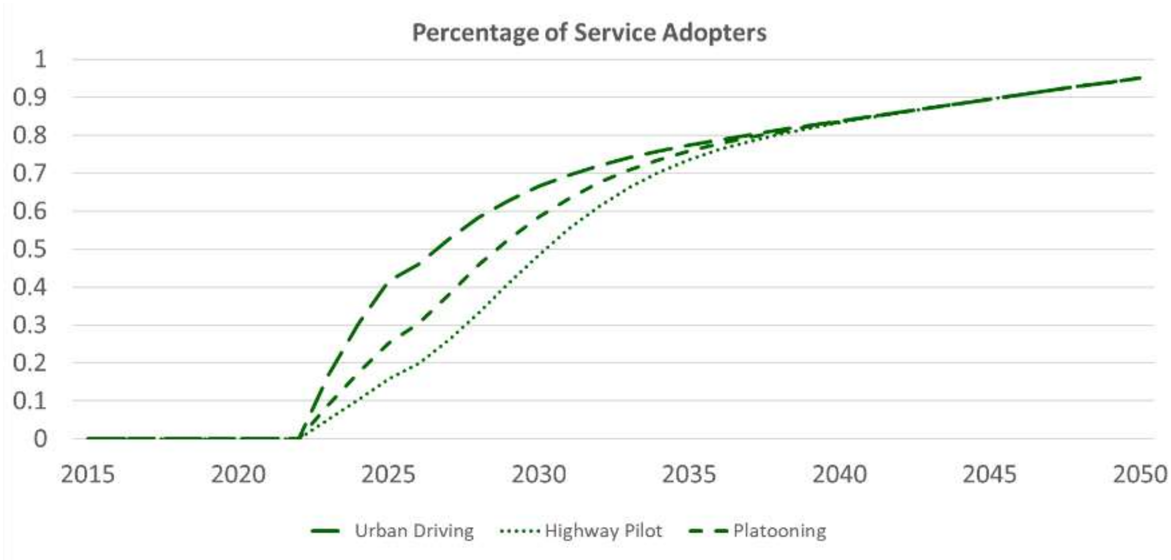


Figure 24 – Percentage of HAV users who adopt the AUTOPILOT services.

The uptake of automation was shown to vary with service availability. The results show that under the base scenario conditions, the AUTOPILOT services could contribute to a 20 % market share of highly automated vehicles by 2050, meaning automation would account for over half of the fleet rather than around a third. Also, as would be expected, it showed that with more services available the adoption is increased.

It is recognised that these services are illustrative due to the assumptions made, but there is evidence that services such as these which impact on the utility of AVs are important for sustained market success and will enhance, accelerate and enable the uptake of AVs.

4.2.3 Impact on quality of life

Outputs related to QoL were built in to the base model described in this chapter. They were derived from the *Fleet Size*. The choice of these outputs to reflect QoL are drawn from the framework for

Impact Assessment pathways prepared by the Trilateral Working Group (Europe, US, Japan) on Automation in Road Transportation (ART WG). In the SD assessment, QoL outputs are determined from the distance travelled by car per person and the changing fleet size.

From the original model and NL data (CBS 2014), the average daily travel by car in the Netherlands in 2014 per person is 15.6km. In the Netherlands in 2015 (the start of our model period), the population of the Netherlands was around 17m and there were around 8m registered vehicles, Thus the average daily travel per car is 33km. May et al. (2019) suggest that for a fleet of almost 100% shared ownership HAV in 2050, car-km can be up to 141% greater than in a fleet with no highly autonomous vehicles and per-car-km can be 148% greater. It was assumed that HAV use is this much greater throughout the duration of the scenario. Daily per person mileage may change over time due to other factors, but this is not accounted for this in the model. The share of road mileage between road types (urban, rural and motorway) are taken from statistics by the UK Department for Transport, as Dutch statistics were not forthcoming. Similarly, emission factors were taken from UK data (National Atmospheric Emissions Inventory). It is additionally noted that these emission factors do not account for electrification or decarbonisation of the fleet, not the intricacies of emission reduction potential from AV services (such as platooning). Finally, speed on different road types, also based on a UK methodology (Ricardo, 2018), was used to determine travel times and the proportion of time spent travelling in automated mode was assumed (L3 = 0.1, L4 = 0.75, L5 = 1).

As the QoL indicators were derived from fleet it is recognized that only limited insights can be drawn. In the absence of the advanced IoT services being developed within AUTOPILOT, we have shown that uptake of highly automated vehicles is likely constrained relative to a scenario where these vehicles are considered to be fully operational. As a result of this, L3 vehicles dominate the market by 2050. Although offering automated driving in certain situations, this reduction leads to reduced travel in automated mode and thus less efficient driving styles may lead to potential excess emissions and energy use. However, if as assumed in our model that highly automated vehicles lead to increased mileage then any benefits of efficient driving may not be realised. This could be counteracted if automated vehicles are introduced within the sharing economy and there is a transition away from the current model of the private owner-user of vehicles, thus there would be fewer vehicles on the road and less ‘empty’ mileage (assuming the fleet is the correct size to efficiently meet demand). There are some health benefits in the highly automated scenario, such as reduced pollution-related disease burdens and risk of traffic incidents. However, the latter may be bias to those who use a fully automated vehicle, whereas individuals in a conventional vehicle or engaging in active travel (often arguably amongst the most vulnerable) may be subject to increased risk of injuries.

5 Implications for societal quality of life

5.1 Relation between impact areas and quality of life

In AUTOPILOT quality of life has three main building blocks which are *public health, individual quality of life* and *equity.* The implications on these areas are considered to derive from impacts of IoT and AD on traffic safety and efficiency, the environment and personal mobility. Table 6 shows the assumed linkages between the impact areas and quality of life.

Smoother vehicle operations and increased driving quality due to IoT in automated driving have potential to increase traffic efficiency, reduce delays and reduce emissions. This can be beneficial for citizens' well-being, health as well as equity. However, these benefits are offset with an increase in travel demand. Further, benefits are not certain as they depend on the programmed behaviour of AVs as well as other road users and their interactions, as well as related phenomena such as behavioural adaptation.

Table 6 – Links between impact areas and Societal quality of life. X denotes linkage, (x) indirect linkage.

		Public health		Individual QoL				Equity		
		Morbidity	Mortality	Social well-being	Physical well-being	Mental well-being	Economic well-being	Social equity	Economic equity	Regional equity
Safety	Nr. of crashes	x	x	x	x	x				
	Severity of crashes	x	x	x	x	x				
Efficiency	Capacity			x					x	x
	Throughput								x	x
	Delays			x			x			x
	Peak period travel time			x			x		x	
Environ-ment	Emissions	x	x		x					x
	Energy use						x		x	x
	Materials use									
	Noise	x			x	x				x
Travel Behaviour	Modal share	(x)	(x)	x	x	x	x	x	x	x
	Nr of journeys	(x)	(x)	x	x		x			
	Dur. and length of journeys	(x)	(x)		x	(x)		x	x	x
Land use	Need for parking space			x	(x)			x		x

5.2 Health

Health was found to be affected through safety, environment and travel behaviour. The direct impacts of safety, efficiency and environment on public health are not clear, mainly due to the uncertainties related to speed behaviour, interaction with other road users and behavioural adaptation. In addition, indirect impacts due to change in accident risk (e.g. due to change of travel mode and/or road type used) and exposure (e.g. route selection, number of journeys) are unknown and have a large influence on the direct effects.

Due to the increased comfort and convenience especially with the AVP AD mode, it can be expected that travel behaviour is likely to change in favour of (personal) car use. This is likely to affect health in negative ways, e.g. by reducing the amount of active travel modes (walking and cycling, including walking to public transport stops). Also the exposure to emissions may increase, which is negative for health.
The main factors influencing public health considered in this study are frequency and severity of accidents, physical activity and exposure to emissions. Deaths in road traffic affect all age groups and therefore mortality, which takes into account the age at which death occurs.

The use of AD modes can decrease driving speeds. As speed is a major factor in accidents, the AD modes could contribute in decreasing the number of injuries and their severity in an accident, leading to positive impacts on morbidity. Emissions and pollutions are injurious effects of road transport affecting morbidity. Because they can be somewhat reduced with the IoT functions, the impact on morbidity would be positive.

Active transport modes such as walking and cycling are considered as physical activity and beneficial to human health and well-being (provided that the conditions are right, e.g. safe infrastructure, sufficiently clean air). If automated vehicles become easily available and affordable for everyone, it is possible that physical activity will decrease. This may lead to a more passive lifestyle, which has disbenefits for health. This effect has been observed e.g. in cities where public transport has been offered free of charge to citizens: people increasingly use the bus instead of active transport modes for short trips.

5.3 Well-being

Individual quality of life, or well-being, was found to be affected through all impact areas: safety, efficiency and environment, travel behaviour and land use (need for parking space). Social, physical and mental well-being can increase or decrease, depending on the changes in injury accidents and their severity. Changes to social well-being are also dependent on traffic efficiency, travel behaviour and land use (regarding AVP), with unclear impact directions. For physical well-being the impact areas are mainly the same as for health: traffic safety, environment and travel behaviour. Changes to mental well-being is thought to be mainly affected through safety, noise and modal share, while changes to economic well-being depend on efficiency and travel behaviour. All impact directions are unclear. Changes in travel behaviour have large indirect potential on the direct impacts considered.

Social well-being can improve with an increase in accessibility due to new travel options. On the other hand, if AD modes lead to an increase in car travel, this may discourage use of active transport and decrease physical activity, which can lead to decreased physical and mental well-being. Further, increased car travel may offset the benefits mentioned above.
Regarding AVP, the decrease of traffic looking for parking spaces as well as the potential decrease in street-side parking lots may benefit active travel modes by freeing up more space for pedestrian walkways and cycle lanes. Enhanced detection of VRU and other road users may increase physical,

mental and social well-being of these groups.

5.4 Equity

A fair transport system provides sufficient accessibility for all under most circumstances (Martens 2016). Insufficient suitable transport options are a main obstacle for overcoming poverty and unemployment and meeting daily needs (Alonso Raposo et al. 2019). IoT and AD has potential to either improve or decrease social, economic and regional equity, depending on the implementation and uptake.

Due to the additional equipment needed, the first AV coming to the market are likely to be expensive. This might limit benefits to wealthier individuals (Milakis et al. 2017), leading to deterioration of economic and social equity. According to Milakis et al. (2017), this scenario would also have several indirect consequences. Regarding traffic safety, if automated vehicles prove to be safer than conventional ones for the drivers and passengers, also safety benefits may distribute unevenly. Further, in the long run, potential spread of activities and reduction of public transport offering may limit access to activities from people without access to AV.
These disbenefits for equity can be mitigated e.g. with policy measures limiting individual use and encouraging reasonably priced shared automated vehicles. For example, an increase in shared mobility services together with decreased need for parking space could then increase housing affordability and improve social and economic equity.

Equity was found to be affected through efficiency and environment, travel behaviour and land use (need for parking space). Changes to social equity are dependent on travel behaviour and land use (For AVP). Changes in economic and regional equity are mainly formed by efficiency, environment and travel behaviour. Again, impact directions are unclear, and changes in travel behaviour have large indirect potential on the direct impacts considered.

Social, economic and *regional equity* may improve somewhat with IoT because the conditions to provide information to users and cover more regions and circumstances would be better. The price of automated transport services is critical in deciding whether IoT would improve people’s access to work, recreation or medical care.

6 Discussion

6.1 Challenges encountered

The challenges encountered in to the quality of life assessment are twofold: First, automated driving itself is a concept in development, and highly automated vehicles do not yet drive on public roads. (The number of partially automated vehicles is also rather low.) Therefore it is challenging to determine the impacts of automated driving itself, and even more to assess the potential additional impacts of IoT.

Second, the transport system is a complex entity, which includes many different impact areas and interactions between them that are not possible to cover entirely in the scope of this research.

6.1.1 Automated driving pilots

Pilot tests of automated driving are challenging. As the vehicles in the pilot tests are experimental prototypes, there are limitations on where, when and by whom they are allowed to operate. For safety reasons it is necessary that a professional operator is inside the cars when testing automated vehicles. It is not always possible to conduct tests in real traffic conditions.

In addition, it is difficult to determine what the automated driving in the pilots should be compared with, i.e. what is selected as a baseline of the assessment. Therefore, the taken impact assessment approach is flexible allowing for exploration and iteration during the course of the project.

All opportunities to collect information on user experiences and expert opinions were taken into account. Potential end users were involved as passengers in the automated vehicles, where possible and feasible.

6.1.2 Transport system complexity

Transport systems are “internally complex systems, made up of many elements influencing each other both directly and indirectly, often nonlinearly, and with many feedback cycles” (Cascetta 2009, Alonso Raposo et al. 2019). Transport policies can be far-reaching and have significant impacts for example on economy, land use, environment, quality of life and social cohesion (Alonso Raposo et al. 2019). These policies may cater for conflicting interests. Dealing with these complexities is necessary for ensuring effective and resilient policies, but it is a challenging task.

The objectives of individual and societal quality of life may be conflicting: for example, improving personal mobility on an individual level may cause traffic system related issues, such as an increase in VKT, if individual motorised travel modes become more attractive than public transport or walking and cycling. Contrarily, technology may lead to improvements on the traffic system level that are not necessarily directly observable as benefits to users. Figure 25 provides a conceptual framework regarding these conflicts. The work in this study focuses on the societal perspective.

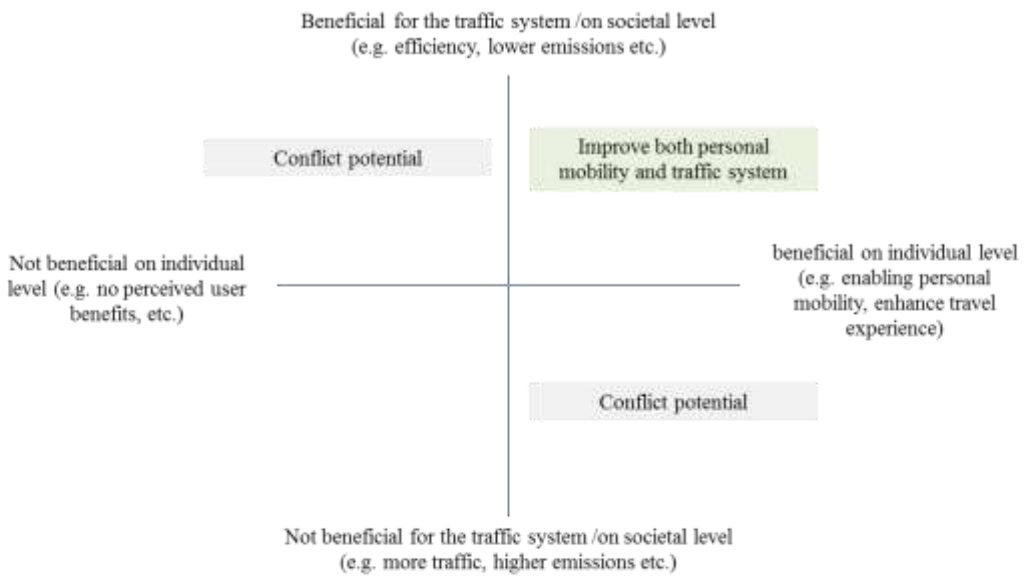


Figure 25 – Dimensions for personal and social mobility (Kolarova et al. 2018).

Policy makers have an important role in determining these scenarios and the role that AV will assume in local, regional and global transportation systems (Dean et al. 2019). It has been hypothesised (Sinasic and Wray 2017) that the degree of AV regulation is most important for determining economic, social, environmental and health impacts of AV. Therefore, all stakeholders should cooperate to ensure equitable distribution of health impacts of AV. Without intervention by regulators, AV capability will likely be tailored by manufacturers to the demands of individual users, and the maximum benefits for safe and efficient operation of the road network may not be obtained (Atkins 2016). Thus, a key question for policy makers is how CAV can best provide network-wide benefits related to AV capabilities, penetration rate and uptake (Atkins 2016).

The need for new governance is highlighted also by Alonso Raposo et al. 2019. If private vehicle ownership remains the norm, the projected increase in travel demand will likely pose challenges to the system. If that happens, it is important to have alternative governance approaches to help deal with the emerging issues. In addition, new governance models are needed in the short run for managing the interaction of new technologies and conventional vehicles.
Public authorities will have greater responsibility in the future, to ensure that the potential that new technologies offer, is used to create a more efficient and sustainable transport system (Alonso Raposo et al. 2019). New governance of the multimodal transport system is necessary and should cover cooperation among all involved actors.

Vehicle design is focused on user comfort and safety. To meet users' demands, vehicle manufacturers are likely to implement AV operations that resemble human behaviour rather than being optimised for traffic smoothing (Makridis et al. 2018, Alonso Raposo et al. 2019, Atkins 2016). As traffic efficiency requires optimising different parameters than comfort and safety, it is not likely that it will be a top priority of vehicle manufacturers. Therefore, unless there are significant policy measures to ensure this, all potential benefits for a safe and efficient operation of the road network may not be obtained (Atkins 2016).

6.2 Potential of AUTOPILOT services

The AD modes piloted in AUTOPILOT were assessed to have potential benefits as well as risks. Many studies have concluded that improvement in the service level of existing traffic conditions can only be expected with efficient and effective vehicle-to-vehicle communication in use (Alonso Raposo et al. 2019). As has been shown in the AUTOPILOT project, IoT is one way of realising this V2V communication. Communication between vehicles and infrastructure can enable better anticipation of events and traffic conditions, and therefore enable smoother driving and faster reaction to events in the road environment.

Potential benefits of IoT and automated driving include smoother driving and more reliable trips due to better anticipation of and reaction to other road users as well as events and road conditions ahead. More accurate and up-to-date information can be sent to the vehicles and users. Smaller variations in speed, a lower speed level in general as well as shorter headways between vehicles and better anticipation offer potential improvements to traffic safety, efficiency and the environment. Travel comfort and convenience are expected to increase.

Potential risks of IoT and automated driving are a shift in mode choice from active travel modes and public transport to personal cars, which can lead to increases in emissions and decline in efficiency and safety, and cyber security issues.

The AD modes Urban driving – Signalised intersection and VRU detection as well as the Hazard warning AD mode for highways are focused on very specific events and conditions. They may be suitable for use in specific areas, such as near schools or in city centres. However, the system point of view should be kept in mind. If the systems are in place in some locations but not in others, it may affect manual drivers' behaviour in a negative way if they put too much trust and responsibility to the systems. Also other road users, especially VRU, can be affected.

What can be determined from the system dynamic model applied within the QoL study is that of the variables that were selected to represent IoT provision and AUTOPILOT use cases, utility weighting would have the most influence on automated vehicle penetration under all scenarios and conditions. A low utility value can lead to market failure even under favourable conditions and high quality IoT provision. Although higher quality provision of IoT does not appear to offer great improvements on automated vehicle uptake compared to the base conditions, it is noticeable that poorer quality IoT could inhibit uptake.

It was assumed that car driving may increase with increased comfort of driving. Increase in car driving would also mean increase in emissions and pollutions. This effect is, however, dependent on several factors and policies applied in the transport system and in the society. The role of active travel modes is assumed to be important regarding physical well-being and health. If motorised driving is going to increase at the cost of active modes contributing in physical health, some negative impacts on wellbeing are expected.

It needs to be kept in mind that many of the estimated impacts, positive and negative, are dependent on the penetration rate of the AD modes in the vehicle fleet. In addition, benefits can be offset and potential disbenefits amplified by an increase in personal car use. Further, the results are only valid with the assumptions made in the assessment (IoT is in place and working). Many uncertainties remain in the development and deployment of automated driving.

For reasons of simplicity, interaction effects between different impact areas were not considered in this analysis. However, in reality there may be significant interaction effects especially with increasing penetration rate of the AD modes. Lower speeds and more harmonised traffic in general as well as enhanced detection can increase the attractiveness of active travel modes in comparison with private cars. This is expected to lead to increased equity and better well-being and health. However, if private car use increases significantly, congestion may again increase, leading to adverse impacts for traffic safety, efficiency and the environment. This may again lower attractiveness of private cars and increase attractiveness of public and active travel modes.

7 Conclusions and recommendations

The quality of life evaluation framework applied in this assessment combines subjective and objective data from different sources. It is based on a framework developed by experts from three regions (EU, US, Japan). The framework was applied to the five general AD modes tested in the AUTOPILOT project. This approach, using the assessment framework as a basis, ensured that the potential impacts were considered systematically, including different potential impact mechanisms and both direct and indirect impacts. Due to the uncertainties and complexities related to vehicle automation and the transport system in general as well as limitations of the pilots it was not possible to perform quantitative analyses. Instead, an analysis of the impact mechanisms related to IoT and automated driving and the potential directions of impacts on traffic safety, efficiency and the environment as well as personal mobility was performed. Based on these results, conclusions of the potential of the AD modes on improving societal quality of life were formed. Benefits for traffic are expected mainly through improved anticipation and reaction to events in the road environment, enabling smoother driving, but negative impacts for example in interaction between road users and behavioural adaptation can counteract. In addition, all potential benefits can be offset by an increase in private car use. The AD modes are expected to increase comfort of car users, which may lead to favouring car use over other travel modes.

In summary, the assessment showed that AUTOPILOT AD modes have potential to improve quality of life, but benefits are not self-evident. Due to the complexity of the transport system and uncertainties in the development and deployment of automated driving and connectivity with IoT, impacts are difficult to estimate. Personal mobility and travel patterns have a large influence on the size and direction of impacts.

Based on the findings, some recommendations for improving societal quality of life with connected automated driving can be made on a general level. The impacts on quality of life are to a large extent dependent on how the AD services are implemented, deployed and regulated. Policy makers should be aware of the potential impacts, positive and negative, in order to make sure that objectives for sustainable and liveable cities can be achieved. The role of regulation and policy making on the impacts of automated driving is substantial. The form of deployment of the AD services has a large influence on the potential impacts. Shared mobility services appear to have more potential for benefits than private vehicle use (Rämä et al. 2018). Integrated city and transport planning can help to facilitate walkable and cyclable cities and prevent a decrease of physical activity by use of active travel modes. The system-dynamic modelling showed that IoT has potential to enhance the uptake of automated driving, which further emphasises the importance of policy making and regulation.

The degree of AV regulation is considered a prime factor determining the economic, social, environmental and health impacts of AVs (Sinasic and Wray 2017). In order to avoid increased use of personal cars due to their increased comfort and convenience that is enabled by the AD modes, their regulation in urban areas could be considered. The potential of shared mobility services and flexible public transport should be facilitated. IoT has potential to improve also these modes, e.g. by helping ride sharing as in the Brainport platooning AD mode. Work of and cooperation between all stakeholders is crucial to ensure that population health impacts as well as their equitable distribution are priority considerations as regulators develop their response to AVs (Dean et al. 2019).

Dean et al. (2019) conclude their scoping study of AV health impacts by recommending that public health and transportation officials should actively monitor trends in AV introduction and adoption, regulators should focus on protecting human health and safety in AV implementation, and researchers should work to expand the body of evidence surrounding AVs and population health.

These conclusions support the findings of the work in AUTOPILOT, and can be widened also to cover the other aspects of societal quality of life, namely well-being and equity.

The methodology developed and presented in this work allows for all the available, rather fragmentary, information on potential impacts of CAD, based on the piloted AD modes in AUTOPILOT, to be utilised without losing sight of the big picture, that is the complex system formed by the several interrelated impact mechanisms, where changes to one mechanism can have both negative and positive impacts on others. All available fragmentary information is brought together in a systematic way. This allows starting to form the bigger picture, learning more about the *Blocks 3* and *4* of Figure 1, where the impacts on the transport system and quality of life are described. The method also allows for following the paths back, from impacts towards factors that play a role in positive or negative impacts. The methodology can be applied to future pilots of automated driving as well. It is recommended that more real-world data be collected in future pilot tests and FOTs in order to gain more insight on the size and direction of potential impacts in the different impact areas identified, and complete gaps in the fragmented data.

Future work on system dynamic models such as the one developed within this work would benefit on considering the role of the automobiles within the wider transport system rather than being central to it, further integration of health-related measures, incorporating powertrain and energy technology transitions, detailing the future mobility sharing economy, considering user costs and social inequities, and expanding to include spatial elements that can address accessibility issues.

It is important to note that the results of this work are theoretical. It is assumed that connectivity between vehicles and infrastructure is available, widely in use and working as intended.
Therefore, the results disregard potential challenges in uptake and deployment of the services.
However, as the objective of the work was to identify the most relevant impact mechanisms, rather than try to produce numerical estimates, which would have to be uncertain, this does not pose a limitation to the work.

8 References

AAA (2019). Automatic Emergency Braking with pedestrian detection. American Automobile Association, October 2019.

Aittoniemi, E., Rämä , P., Kuisma, S., Malin, F., Kahilaniemi, S., Mustajärvi, A., Coconea, L., Schünemann, B., Häusler, F., Ordinez, R. (2016). Impacts of TEAM applications. D5.5.1 of Tomorrow's Elastic Adaptive Mobility (TEAM) FP7 project.

Alonso Raposo, M. (Ed.), Ciuffo, B. (Ed.), Ardente, F., Aurambout, J-P., Baldini, G., Braun, R., Christidis, P., Christodoulou, A., Duboz, A., Felici, S., Ferragut, J., Georgakaki, A., Gkoumas , K., Grosso, M., Iglesias, M., Julea, A., Krause, J., Martens, B., Mathieux, F., Menzel, G., Mondello, S., Navajas Cawood, E., Pekár, F., Raileanu, I-C., Scholz, H., Tamba, M., Tsakalidis, A., van Balen, M., Vandecasteele, I., The future of road transport - Implications of automated, connected, low-carbon and shared mobility, EUR 29748 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-03409-4, doi:10.2760/9247, JRC116644.

Atkins. (2016). Research on the impacts of connected and autonomous vehicles (CAVs) on traffic flow Stage 1: Evidence Review, (March), 58. Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/530091/impacts-of-connected-and-autonomous-vehicles-on-traffic-flow-summary-report.pdf

Atkinson, S. (2013) Beyond Components of Wellbeing: The Effects of Relational and Situated Assemblage, Topoi. doi: 10.1007/s11245-013-9164-0.

Bruni, L. and Porta, P. L. (eds.) (2007) Handbook on the Economics of Happiness, Edward Elgar Publishing.

Carse, A. (2011) Assessment of transport quality of life as an alternative transportappraisal technique, Journal of Transport Geography. doi:10.1016/j.jtrangeo.2010.10.009.

Carsten, O., Tate, F. (2005) Intelligent speed adaptation: accident savings and cost-benefit analysis. Accident Analysis and Prevention 37 (3) 407-416.

CBS (2014). Onderzoek Verplaatsingen in Nederland (OViN) 2014. https://www.cbs.nl/nl-nl/onze-diensten/methoden/onderzoeksomschrijvingen/korte-onderzoeksbeschrijvingen/onderzoek-verplaatsingen-in-nederland--ovin--.

Carsten, O., Saint Pierre, G., Olstam, J., Mejuto, P., Winder, A., Kooijman, D., Brouwer, R., Jamson, S. (2016). Final publishable summary. D1.6 of ecoDriver project, version 1 12.06.2016.

Cascetta, E. (2009). Transportation Systems Analysis: Models and applications. Springer Science & Business Media.

Cavoli, C., Phillips, B., Jones, P. (2017) Social and behavioral questions associated with Automated Vehicles. A Literature Review, London: Department for Transport.

Clark, B.; Parkhurst, G., Ricci, M. (2016) The potential impact of autonomous vehicles on transport systems and society: A review and future prospects. In: 48th Universities' Transport Studies Group Conference, Bristol, UK, 6-8 January 2016.

Cyganski, R., Fraedrich, E., Lenz, B. (2015). Travel-time valuation for automated driving: a use-case driven study. In: Proceedings of the 94th Annual Meeting of the TRB, 11.-15. January 2015, Washington, D.C, USA.

Daschkovska, K., Moeller, J., Bogaschewsky, R. (2019). Smart Mobility: Challenging issues and new opportunities in a sustainable smart city. The 24th International Symposium on Logistics (ISL 2019), 14th – 17th July 2019At: Würzburg, Germany

Dean, J., Wray, A., Braun, L., Casello, J., McCallum, L., Gower, S. (2019). Holding the keys to health? A scoping study of the population health impacts of automated vehicles. BMC Public Health 2019 19:1258. https://doi.org/10.1186/s12889-019-7580-9.

Diels, C., Erol, T., Kukova, M., Wasser, J., Cieslak, M. P., Payre, W., Bos, J. (2017). Designing for Comfort in Shared and Automated Vehicles (SAV): a Conceptual Framework. Paper presented at International Comfort Congress, Salerno, Italy.

Eilbert, A., Berg, I., Smith, S. B. (2019). Meta-Analysis of Adaptive Cruise Control Applications: Operational and Environmental Benefits. Fhwa-Jpo-18-743, (August), 30. Retrieved from https://rosap.ntl.bts.gov/view/dot/41929

Elvik, R., Vadeby, A., Hels, T., van Schagen, I. (2019). Updated estimates of the relationship between speed and road safety at the aggregate and individual levels. Accident Analysis & Prevention, Volume 123, 2019, Pages 114-122, ISSN 0001-4575, https://doi.org/10.1016/j.aap.2018.11.014.

Endsley, M. R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. Human Factors, 37(1), 32–64.

Ertl, D., Aittoniemi, E., Barnard, Y., Haibo, C., Harrison, G., Kolarova, V., Malin, F., Touliou K. (2018). User requirements analysis. AUTOPILOT project Deliverable 4.7.

Ertl, D., Aittoniemi, E., Barnard, Y., Haibo, C., Harrison, G., Kolarova, V., Malin, F., Touliou K. (2019). User acceptance assessment. AUTOPILOT project Deliverable 4.8.

European Commission (2016). A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2016) 766 final.

Fagnant, D. J. and Kockelman, K. (2015) Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. Transportation Research Part A: Policy and Practice. 77, pp. 167-181.

Felce, D., Perry, J. (1995). Quality of life: Its definition and measurement. *Research in Developmental Disabilities, 16*(1), 51–74. https://doi.org/10.1016/0891-4222(94)00028-8

Fraedrich, E., Lenz, B., Maurer, M., Gerdes, J.C., Lenz, B., Winner, H. (2016). Taking a drive, hitching a ride: autonomous driving and car use. In: Autonomous Driving. Technical, Legal and Social Aspects. Springer, 665–685.

Gerla, M., Lee, E. K., Pau, G., & Lee, U. (2014). Internet of vehicles: From intelligent grid to autonomous cars and vehicular clouds. In 2014 IEEE world forum on internet of things (WF-IoT) (pp.

241-246). IEEE.

Geum, Y., Lee, S., Park., Y. (2014). Combining technology roadmap and system dynamics simulation to support scenario-planning: A case of car-sharing service. Computers and Industrial Engineering, 71, 37 - 49.

Gouy, M. (2013). *Behavioural adaption of drivers of unequipped vehicles to short time headways observed in a vehicle platoon* (Doctoral dissertation, The Open University).

Gouy, M., Wiedemann, K., Stevens, A., Brunett, G., Reed, N. (2014). Driving next to automated vehicle platoons: How do short time headways influence non-platoon drivers' longitudinal control?, Transportation Research Part F: Traffic Psychology and Behaviour, Volume 27, Part B, 2014, Pages 264-273, ISSN 1369-8478, https://doi.org/10.1016/j.trf.2014.03.003.

Gruel, W., Stanford, J. (2015). Assessing the Long-Term Effects of Autonomous Vehicles: a speculative approach. European Transport Conference 2015 – from Sept 28 to Sept-30, 2015.

Gustafsson, P., Muñoz, J. C., Lindgren, L., Boda, C-N., Dozza, M. (2013). BikeCOM: cooperative safety application supporting cyclists and drivers at intersections. Proceedings of the 3rd International Conference on Driver Distraction and Inattention, September 4-6, 2013, Gothenburg, Sweden.

Harrison G., Shepherd S., Chen H., Barnard Y. (2019). Benefits and uptake sensitivities of connected automated vehicles. European Transport Conference 2019.

Innamaa, S., Axelson-Fisk, M., Borgarello, L., Brignolo, R., Guidotti, L., Martin Perez, O., Morris, A., Paglé, K., Rämä, A., Wallgren, P. & Will, D., 2013. Impacts on Mobility – Results and Implications. TeleFOT deliverable D4.4.3, European Commission, Information Society and Media, 7th Framework Programme.

Innamaa S., Smith S., Barnard Y., Rainville L., Rakoff H., Horiguchi R., Gellerman H., 2018. Trilateral impact assessment framework for automation in road transportation, version 2.0. Trilateral impact assessment sub-group for ART.

Innamaa S. (2019). Impact Pathways for automated driving [presentation]. Workshop on Automated Vehicle Impact Pathways. 10 April 2019, Leeds, UK. Trilateral impact assessment sub-group for ART.

Kahneman, D., Diener, E., and Schwarz, N. (eds.) (1999) Well-Being: the Foundations of Hedonic Psychology, Russell Sage, New York.

Kim, Y. (2007). A System Dynamics Model for the Technological Forecasting of Automotive in-car Navigation Market. 2007 International Forum on Strategic Technology, 3-6 Oct. 2007. Ulaanbaatar, Mongolia: IEEE.

Kolarova, V., Müller, S., Koller, F. and Bahamonde-Birke, F. (2018). Potenziale, Herausforderungen und Wirkungen des automatisierten und vernetzten Fahren. In: Arbeitsberichte zur Verkehrsforschung. ISSN: 2513-1699

Kolarova, V. Cyganski, R., Lenz, B. (2019). Activities while travelling? Travel time perception and travel time use in an era of automated driving. In Ben-Elia, E. (Ed.). (2019). The Evolving Impact of ICT on Activities and Travel Behaviour (Vol. 3). Academic Press.

Krytska, Y., Skarga-Bandurova, I., and Velykzhanin, A., Dahl, V. (2017) IoT-based Situation Awareness Support System for Real-Time Emergency Management. The 9th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, 21-23 September, 2017, Bucharest, Romania.

Kulmala, R. (2010). Ex-ante assessment of the safety effects of intelligent transport systems. Accident Analysis & Prevention 42, 1359–1369.

Kulmala, R., Leviäkangas, P., Sihvola, N., Rämä, P., Francsics, J., Hardman, E., Ball, S., Smith, B., McCrae, I., Barlow, T., Stevens, A. (2008). Deliverable 5 Final study report of Co-Operative Systems Deployment Impact Assessment (CODIA) project, Espoo, Finland, 174 p.

Kyriakidis, M., Happee, R., & De Winter, J. C. F. (2015). Public opinion on automated driving: Results of an international questionnaire among 5000 respondents. Transportation Research Part F: Traffic Psychology and Behaviour, 32, 127–140. https://doi.org/10.1016/j.trf.2015.04.014

Lee, R. and Sener, I. (2016) Transportation planning and quality of life: Where do they intersect?, Transport Policy. doi: 10.1016/j.tranpol.2016.03.004

Lemmer, K. (Ed.). (2019). Neue autoMobilität II. Kooperativer Straßenverkehr und intelligente Verkehrssteuerung für die Mobilität der Zukunft. utzverlag GmbH.

Makridis, M., Mattas, K., Ciuffo, B., Alonso, M., Tomer, T., Thiel, C. (2018). Connected and automated vehicles on a freeway scenario. Effect on traffic congestion and network capacity. 7th Transport Research Arena TRA.

Malone, K., Verroen, E., Korver, W., Heyma, A. (2001). The Scenario Explorer for Passenger Transport: A Strategic Model for Long-term Travel Demand Forecasting. Innovation: The European Journal of Social Science Research, 14, 331-353.

Malone, K., Rech, J., Hogema, J., Innamaa, S., Hausberger, S., Dippold, M., van Noort, M., de Feijter, E., Rämä, P., Aittoniemi, E., Benz, T., Burckert, a., Enigk, H., Giosan, I., Gotschol, C., Gustafsson, D., Heinig, I., Katsaros, K., Neef, D., Ojeda, L., Schindhelm, R., Sütterlin, C., Visintainer, F. (2014). Impact assessment and user perception of cooperative systems, Deliverable 11.4 of Driving Implementation and Evaluation of C2X Communication Technology in Europe (DRIVE C2X) project 274 + 50 p.

Marshall, P. (2015). System dynamics modeling of the impact of Internet-of-Things on intelligent urban transportation. 2015 Regional Conference of the International Telecommunications Society (ITS), 25-28 October, 2015. Los Angeles, CA,: International Telecommunications Society (ITS).

Martens, K. (2016). Transport justice: Designing fair transportation systems. Routledge.

Mathews, E., Schmeitz, A., Jansen, S., Alen, S., Alvarez, M., Cabrero Barros, S., Chapuis, C., Copel, D., David, M., Falcitelli, M., Gkragkopoulos, I., Kahale, E., Kaul, R., Marcasuzaa, H., Martínez, J.M., Monroy, M., Nikolaou, S., den Ouden, J., Petrescu, A., Simeon, J.-F., Schreiner, F., Scholliers, J., Simonetto, A., Teerhuis, A., Touko Tcheumadjeu, L., Vivero, A., Zougari, S. (2019). Final Specification of IoT-enabled autonomous driving use cases. AUTOPILOT deliverable D1.2.

May, A., Shepherd, S., Pfaffenbichler, P., Emberger, G. (2019). The potential impacts of automated cars on urban transport: an exploratory analysis. World Conference on Transport Research - WCTR

2019 Mumbai Transport Research Procedia.

Milakis, D., Arem, B. Van, & Wee, B. Van. (2017). Policy and society related implications of automated driving : A review of literature and directions for future research. Journal of Intelligent Transportation Systems, 21(4), 324–348. https://doi.org/10.1080/15472450.2017.1291351

Milanes, V., Shladover, S. E., Spring, J., Nowakowski, C., Kawazoe, H., & Nakamura, M. (2014). Cooperative adaptive cruise control in real traffic situations. IEEE Transactions on Intelligent Transportation Systems, 15(1), 296–305. https://doi.org/10.1109/TITS.2013.2278494

Minerva, R., Biru, A., Rotondi, D. (2015) Towards a Definition of the Internet of Things (IoT). IEEE Internet of Things Iniative.

Mäkinen, R. (2019. Impacts of Automated Driving on Health and Quality of Life: Master's thesis. VTT Technical Research Centre of Finland. https://doi.org/10.32040/2242-122X.2019.T360

Netten B., Aittoniemi E., Barnard Y., Federley M., Gaitanidou L., Karagiannis G., Kolarova V., Lenz O., Pont Rañé J., Van den Boom B., Willenbrock R. (2018). Methodology for evaluation. AUTOPILOT deliverable D4.1.

Nieuwenhuijsen, J., Correia, G. H. de A., Milakis, D., van Arem, B., & van Daalen, E. (2018). Towards a quantitative method to analyze the long-term innovation diffusion of automated vehicles technology using system dynamics. Transportation Research Part C: Emerging Technologies, 86(May 2017), 300–327. https://doi.org/10.1016/j.trc.2017.11.016

Noland, R. B. (1995). Perceived risk and modal choice: Risk compensation in transportation systems. Accident Analysis and Prevention, 27(4), 503–521. https://doi.org/10.1016/0001-4575(94)00087-3

Oja, P., Titze, S., Bauman, A., de Geus, B., Krenn, P., Reger-Nash, B., Kohlberger, T. (2011). Health benefits of cycling: A systematic review. Scandinavian Journal of Medicine and Science in Sports, 21(4), 496–509. https://doi.org/10.1111/j.1600-0838.2011.01299.x

Ortúzar, J.d.D., Willumsen, L.G., (2011). Modelling Transport. John Wiley & Sons Ltd., Chichester, UK.

Pakusch, C., Stevens, G., Bossauer, P., Weber, T. (2018). The Users' Perspective on Autonomous Driving – A Comparative Analysis of Partworth Utilities. In Proceedings of the 15th International Joint Conference on e-Business and Telecommunications (ICETE 2018) - Volume 1.

Penttinen, M., van der Tuin, M., Farah, H., de Almeida Correia, G.H., Wadud, Z., Carsten, O., Kulmala, R. (2019) Impacts of connected and automated vehicles - State of the art. MANTRA Deliverable D3.1. MANTRA: Making full use of automation for National Transport and Road Authorities - NRA Core Business. CEDR.

Ploeg, J., Scheepers, B., van Nunen, E., van de Wouw, N., Nijmeijer, H. (2011). Design and Experimental Evaluation of Cooperative Adaptive Cruise Control. In: Proceedings of the 14th International IEEE Conference on Intelligent Transportation Systems (ITSC 2011), Washington D.C., USA, October 5–7.

POLIS European cities and regions networking for innovative transport solutions. (2018). Road Vehicle Automation and Cities and Regions. Brussels. https://doi.org/10.1007/978-3-319-60934-8

Pont, J., Velizhev, A., Dekusar, A., Netten, B., Wedemeijer, H., Firmani, C., di Massa, V., Visintainer, F., Andreetto, M., Karagiannis, G., Walle, L., Viola, L., Solmaz, G., Chen, H., Dave, K., Gao, J., Chen, J., Gomez, D., den Ouden, J., Ijsselmuiden, J., Villar, J., Rial, M., Touko Tcheumadjeu, L., Kaul, R., David, M., Reschka, T., Tiemann, R., Guadalupe Gabian, M., Ben Alaya, M. (2019). Final technical evaluation. AUTOPILOT deliverable D4.3.

Porter M., Heppelmann, J. (2014) How smart, connected products are transforming competition. Harvard Business Review 92:11–64.

Pudāne, B., Rataj, M., Molin, E. J. E., Mouter, N., van Cranenburgh, S., Chorus, C. G. (2019). How will automated vehicles shape users' daily activities? Insights from focus groups with commuters in the Netherlands. Transportation Research Part D: Transport and Environment, 71(December 2018), 222–235. https://doi.org/10.1016/j.trd.2018.11.014

Puylaert, S., Snelder, M., van Nes, R., van Arem, B. (2018). Mobility impacts of early forms of automated driving – A system dynamic approach. Transport Policy, 72, 171-179.

Rämä, P. and Kulmala, R. (2000). Effects of variable message signs for slippery road conditions on driving speeds and headways. Transportation Research F3, 85-94.

Rämä, P. (2001). Effects of Weather-controlled Variable Message Signing on Driver Behaviour. VTT Publications 447. Technical Research Centre of Finland, Espoo.

Rämä, P., Kuisma, S., Steger-Vonmetz, C., Vlk, T., Page, Y., Malone, K., Wilmink, I., Bärgman, J., Macbeth, I., Sumner, G., de Almeida Correia, G. H., Gougeon, P., Wilsch, B., Barnard, Y., Cizkova, T., Alessandrini, A., Nikolaou, S. (2018). Societal impacts of automated driving. CARTRE project Deliverable 5.3. Version 1.0.

Rämä, P. & Koskinen, H. (2019) Exploring Driver and Operator Behaviour Models in the Context of Automated Driving – Identification of Issues from a Human Actor Perspective. VTT Technology 356. DOI: 10.32040/2242-122X.2019.T356

Sallis, J., Cerin, E., Conway, T., Adams, M., Frank, L., Pratt, M., Salvo, D., Schipperijn, J., Smith, G., Cain, K., Davey, R. (2016). Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study. Lancet. 2016;387(10034):2207–17.

Van Schalkwyk, M. C. I., Mindell, J. S. (2018). Current issues in the impacts of transport on health. British Medical Bulletin, 125(1), 67–77. https://doi.org/10.1093/bmb/ldx048

Scholliers, J., Ben Alaya, M., Brevi, D., Dafonte, P., den Ouden, J., Falcitelli, M., Karagianis, G., Kaul, R., Liuxin, W., Maraia, L, Marcasuzaa, H., Netten, B., Nicoud, A.-C., Nikolaou, S., Oh, H.S., Pieri, L., Scalambro, P., Schreiner, F., Simonetto, A., Touko Tcheumadjeu, L., van den Ende, B., Velizhev, A., Viola, L., Yeung, M. (2018). Pilot site adaptation validation report. AUTOPILOT deliverable D3.3.

Schreiner, F., Nicoud, A.-C., Alesiani, F., Altomare, L., Belz, J., Dafonte, P., Daalderop, G., den Ouden, J., di Massa, V., Galli, M., Leskovsky, P., Kahale, E., Marcasuzaa, H., Martinez, J.M., Matta, J., Muro, M., Schmeitz, A., Scholliers, J., Visintainer, F. (2019). Adaptation report of AD functions with IoT technologies. AUTOPILOT deliverable D2.2.

Seligman, M. (2002) Authentic Happiness: Using the New Positive Psychology to Realize Your Potential for Lasting Fulfillment, Free Press/Simon and Schuster, New York.

Shepherd, S. (2014). A review of system dynamics models applied in transportation. Transportmetrica B: Transport Dynamics, 2, 83-105.

Sihvola, N. (2009). Driver assessment of roadweather conditions and roadweather information. Young Researchers Seminar 2009, Torino, 3-5 June 2009, Session 4 – Transport Safety (2).

Sinasic, S. and Wray, A.J. (2017). Autonomous vehicles: savior or sentinel of lowcarbon suburban futures. In: Moos M, Walter-Joseph R, editors. Ed(s). Still detached and subdivided? Suburban ways of living in 21st century North America. Berlin: JOVIS Verlag; 2017. p. 144.

Singleton, P. A. (2017). Exploring the positive utility of travel and mode choice.

Singleton, P.A., 2019. Discussing the "positive utilities" of autonomous vehicles: will travellers really use their time productively? Transp. Rev. 39 (1), 50–65.

Skottke, E.-M., Debus, G., Wang, L., & Huestegge, L. (2014). Carryover Effects of Highly Automated Convoy Driving on Subsequent Manual Driving Performance. Human Factors, 56(7), 1272–1283. https://doi.org/10.1177/0018720814524594

Stanford, J. (2015). Possible Futures for Fully Automated Vehicles: Using Scenario Planning and System Dynamics to Grapple with Uncertainty. PhD Thesis.

Stanton, N. A., and Young, M. S. (2000). A proposed psychological model of driving automation. Theoretical Issues in Ergonomics Science, 1(4), 315–331. https://doi.org/10.1080/14639220052399131

Sterman, J. (2000). Business Dynamics: Systems Thinking and Modelling for a Complex World, Boston, McGraw-Hill Higher Education.

Struben, J. and Sterman, J. (2008). Transition challenges for alternative fuel vehicle and transportation systems. Environment and Planning B: Planning & Design, 35, 1070-1097.

Talebpour, A., Mahmassani, H. (2016). Influence of connected and autonomous vehicles on traffic flow stability and throughput. Transportation Research Part C Emerging Technologies. 71. 143-163.

Thomopoulos, N. and Givoni, M. (2015) The autonomous car--a blessing or a curse for the future of low carbon mobility? An exploration of likely vs. desirable outcomes. European Journal of Futures Research. 3(14).

Trommer, S., Fraedrich, E., Kolarova, V., Lenz, B., 2017. Exploring user expectations on autonomous driving. In: Automated Vehicle Symposium 2016, 19.-21. July 2016, San Francisco, USA.

van der Laan, J., Heino, A., de Waard, D. (1997). A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research - Part C: Emerging Technologies, 5, 1 - 10.

Vreeswijk, J. and Blokpoel, R. (2013). Fuel and emission factors – How much can we realistically reduce with ITS? 9th ITS European Congress, Dublin, Ireland, 4-7 June 2013, (June), 4–7.

Wickens, C. D. (2008). Situation Awareness: Review of Mica Endsley's 1995 Articles on Situation

Awareness Theory and Measurement. Human Factors: The Journal of the Human Factors and Ergonomics Society, 50(3), 397–403. https://doi.org/10.1518/001872008X288420

Wilmink I., Janssen W., Jonkers E., Malone K., van Noort M., Klunder G., Rämä P., Sihvola N., Kulmala R., Schirokoff A., Lind G., Benz T., Peters H., Schönebeck S. (2008). Impact assessment of Intelligent Vehicle Safety Systems. Deliverable 4 of Assessing the Impacts of Intelligent Vehicle Safety Systems (eIMPACT) project, TNO, The Netherlands, 105 p.

Wismans, L. (2012). Towards Sustainable Dynamic Traffic Management, Phd-thesis, TRAIL Thesis Series, University of Twente, Enschede, The Netherlands, 2012.

Woetzel, J., Remes, J., Boland, B., Lv, K., Sinha, S., Strube, G., Means, J., Law., J., Cadena, A., von der Tann, V. (2018) Smart cities: Digital solutions for a more livable future. McKinsey Global Institute.

World Health Organization (1997). Measuring Quality of Life. The World Health Organization quality of life instruments (WHOQOL).

World Values Survey: The World's Most Comprehensive Investigation of Political and Sociocultural Change (2009), Available on-line: http://www.worldvaluessurvey.org/.

Yang, D., Farah, H., Schoenmakers, M. J., Alkim , T. (2019). Human drivers behavioural adaptation when driving next to a platoon of automated vehicles on a dedicated lane and implications on ttraffic flow: a driving simulator and microscopic simulation study in the Netherlands. Manuscript submitted for publication. In Proceedings 98th Annual Meeting of the Transportation Research Board, Washington DC, USA.

9 Annexes

9.1 Annex 1 – Impact mechanisms

9.1.1 Use of AD (*Block 1*)

9.1.1.1 Acceptance

The acceptance of automated driving is linked to the intended acquisition of automated vehicles, specific functionalities or services, as well as their intended use. The user needs to have some knowledge (or at least a mental image, which may not be based on reality) of the automated functions to be able to accept them.
Automation awareness refers here, on one hand, to the user's general knowledge on the automated functionalities, their performance and limitations. The user needs to know of the operational design domain (ODD), i.e. in which driving environments and circumstances the vehicle can drive in automated mode.
Willingness and possibility to have indicates whether the potential user has the means, and whether they intend to acquire or choose (in case of car-sharing) automated functionalities into the car they use. As a mental resource, the potential user needs to have at least some general knowledge about automated functionalities to reliably indicate willingness to have.
Willingness to use is difficult to measure. To some extent it is reflected by actual use, i.e. the share of trips or km the user is willing to use the automation within its ODD; how frequently and in which circumstances the automated functionalities are used. The user may use the functionalities on all trips and in all conditions when the service is available (inside the ODD), or they may be willing to use the systems in specific conditions only, for example on long trips, on motorways or when tired.

9.1.1.2 Transport system

Here, the transport system is outlined as *road* transport system.
Transport management refers to how the whole road transport system is managed; what infrastructure and vehicles are available and how they are controlled, what transport services are offered to the users in the city or other administrative area. Transport management is implemented on local, regional, national, European levels and also covers the relationships and cooperation of different levels.
Operation of vehicles / systems is part of the transport management referring how vehicle fleets - buses, shuttles, robotaxis, platoons of cars or trucks - are operated. It concerns questions such as who is the operator, what is the role of automation, which are the principles or rules of operation at different times of the day (week; other circumstances), are there any priorities, how is multimodality taken care of, etc.
Equipping vehicles with automated functionalities is reflected in the *price of AV*. Price formation of cars and vehicles is influenced also by other parallel changes such as electrification of road transport. Price is dependent on business models (who is going to pay and what, how the costs and profits are shared) and the price setting of AVs for example in car sharing.
Travel costs are formed for example of vehicle costs, moving power costs, leasing costs, ticket costs, parking cost and time costs. It has been suggested that the value of time is going to change with higher levels of automation allowing drivers in road transport to engage in other activities than vehicle operation.

9.1.2 Mileage per mode (*Block 2*)

9.1.2.1 Vehicle operations

The category *Vehicle (control) operations* include the driving behaviour of the AV itself, such as its acceleration, deceleration, lane keeping, car following, lane changing and gap acceptance. Vehicle operation characteristics (driving style) directly affect several other impact areas such as road (network) capacity and road safety. Relevant automation applications include those which provide longitudinal and/or lateral control with respect to the road and other vehicles. (Innamaa et al. 2018).

Car following describes the longitudinal driving behaviour of the AV when following another vehicle, e.g. the time headway to the vehicle in front and its potential changes in time. *Lane keeping* refers to the lateral behaviour of the AV, meaning how well it stays inside a lane and whether there are oscillations in lateral movement. *Lane changes* can be partly automatic, initiated by the driver (with turn signal) or they can be (totally) automatic, initiated by the AV when encountering a vehicle ahead travelling at a slower speed than targeted by the AV or when required to follow the route. In presence of other vehicles in the next lane, AV needs to find suitable gap for the lane change (*gap acceptance* of the AV). Gap acceptance is relevant also for intersections where the AV needs to yield. *Speed behaviour* describes the speed choice of the AV (target speed) and its potential changes in different situations (such as speed variation). There are several detailed indicators to describe speed behaviour such as spot speeds, mean speed, variance of speed. *Interaction with other vehicles and VRUs* refers to all kinds of interactions between the AV and other road participants, such as over-takings, cut-ins, distance kept to other road-users, stopping behaviour at intersections and pedestrian crossings, gap formation at ramps, etc. The category s*afety manoeuvres* includes behaviour programmed into AVs for situations where the driver does not take back control when requested (minimum risk manoeuvres) as well as manoeuvres carried out by the driver, e.g. manual braking or steering if the AV does not seem to handle some situation. The term *situational picture* refers to the interpretation of the situation around the vehicle (the current traffic situation, the road and the environmental conditions) formed on basis of the information available to the vehicle (or driver) from its sensors and via connectivity.

9.1.2.2 AD User

The items under ‘AD user’ address the perspective and experience of the user and their change from being a driver (in manual driving) with increasing automation to being a user (in full automation).
‘Ease of driving, non-driving’ indicates driver experience/opinion on how easy it is to take care of all the dynamic and other driving tasks, but also the possibilities for doing other things than driving during the trip. Non-driving refers to the periods of time where the user does not need to drive, enabled by the AV taking control of the driving task. The length and frequency of non-driving periods are critical for ease of driving. AD may change the nature and extent of *in-car activities* carried out by the user while riding/driving. Ease of driving also refers to making driving easier with low level automation when car support the driving in his/her driving.
The term *workload* refers to the interaction between the task demands and the driver’s capabilities in a certain driving situation. *Situation awareness* incorporates the driver’s understanding of the driving situation as a whole, including e.g. the traffic and (road) weather conditions, and of AV behaviour at any given time of the trip. It refers to perception of the elements in the situation, how their meaning is comprehended and how the status in the near future is anticipated. The focus (relevance) of situation awareness depends on the level of automation: With full automation, it is not necessary for the user to be aware of the driving situation (but they may still like to have the information), whereas in partial automation it is very important. For conditional automation the fast recovery of situation awareness is a challenge when the take back of control is required. Situation awareness is closely related also to the HMI through which the AV and its user communicate (what part of the information available to the vehicle is shown to the user).
Stamina (fatigue) means the energy level or vitality of the driver/user. In long monotonous driving or non-driving situations, e.g. on a motorway with little traffic, drivers may become tired, which has implications on their driving capabilities, to fully utilize the driving skills.
The term ‘*Frequency of take back of control’* relates to situations in conditional automation where drivers are requested to take back control at the end of ODD (system initiated), or they can themselves take back full control of the driving task when preferring to drive by themselves (driver initiated). From the user perspective, it is relevant how often and in which situations the driver

needs to take over control and how early they get the indication of the requested take over. As this take over control situation is potentially risky, its frequency is of interest. Late take over requests may lead to poor situation awareness of the driver when beginning to drive again. The frequency also affects the possibilities for secondary activities during the drive.
Driving experience concerns the experience (mileage) of the user of the AV that s/he drives manually by conditions and by road types. If the AV drives automatically e.g. always when on motorways, the human driver does not get experience of driving on motorway, etc. In the long run, the lack of driving experience affects the driving skills and capabilities.

9.1.2.3 Quality of travel

Quality of travel concerns the characteristics of the AV use from the users' point of view. It includes the following topics: comfort and stress, use of in-vehicle time, traveling reliability and feeling of safety.
Comfort describes whether the ride feels comfortable or uncomfortable (e.g. due to harsh braking or fast longitudinal or lateral acceleration). It can also refer to the convenience of the services enabled by AD. S*tress* refers to the user's emotional stress (uncertainty, fatigue, distress, worry) related to the trip with an AV (e.g. stress due to uncertainty of AV behaviour or take-back-control situations; or decrease of stress due to removed need for searching a parking space or drive (manually) e.g. in congestion). *Use of in-vehicle time* refers to possible non-driving related secondary tasks in the vehicle like use of entertainment, which can be allowed if the driver is not constantly in charge of monitoring the environment. The actual in-vehicle activities depend also on the users' choices, preferences and on e.g. their proneness to motion sickness. The use of in-vehicle time is related to the value of time when traveling.
Traveling reliability in this context means primarily how well the trip duration can be predicted (travel time reliability), but it may also concern other aspects of the trip such as the costs of the journey, reliability of automated services, accessibility and reliability of travel chain. *Feeling of safety* refers to the subjective safety when traveling, i.e. whether the driver feels or experiences that the automated vehicle is driving safely and also ensures the safety of other road users.

9.1.2.4 Transport offering

Transport offering refers to the potential changes in mobility options available to users.
Completely new mobility services can develop due to the introduction of AV (*New possibilities for mobility services).* If useful new services arise to meet people's mobility needs (such as car sharing service, robotaxis, automated shuttles), this may lead to changes in car ownership.
Vehicle availability means certainty that there is a vehicle available for a user when (s)he needs it. This is linked to the mode choice, car ownership and traveling reliability.

9.1.2.5 Driving quality

Driving quality relates largely to the changes in driving behaviour on a vehicle level (*Vehicle operations)* and how well it is able to drive but also on traffic flow level and how smooth it is. Driving quality concerns the translation of impacts on single vehicle operations to the road network in a wider scope. Changes in individual behaviour of vehicles, such as choice of headway and speed, have consequences on the speed patterns of a group of vehicles traveling in the same direction, reflected e.g. as shockwaves within the traffic flow. These sudden behaviour changes of single vehicles and the impact on them on traffic flow level depend on the capabilities of the AV, and the extent of impacts in specific situations depends, among others, on the penetration rate of AVs, their situation awareness and capabilities of car following, as well as on the traffic volume on the road.
Synchronisation of speed patterns may occur with higher penetration rates of AV (or CACC), or in situations where overtaking is not possible and a platoon/queue of vehicles drives with close to equal speed. In manually driven vehicles, keeping a constant speed is not easy, and the speed of individual vehicles typically oscillates around a certain speed. The amount of oscillation depends for example on the state of the driver, possible distracting factors and the surrounding traffic situation.

AVs are better capable of keeping a certain set speed. This is especially true for connected vehicles, which can better anticipate upcoming traffic situations. Synchronised speed patterns lead to a smoother traffic flow with less disturbance, especially relevant for situations with high traffic volume and/or bottlenecks (e.g. accidents, lane closures).

Variance in alignment of driving refers to the lateral alignment of a group of vehicles traveling in the same direction. Lateral position in the lane can affect the abrasion of the pavement and e.g. rut formation, if a platoon of vehicles drives exactly on the same track in a lane.

Driving errors refer to mistakes in driving behaviour by individual vehicles/drivers. On the one hand, automation can reduce driving errors (e.g. by preventing unintended lane departures, obeying the speed limits or by not being distracted when driving), but on the other hand new driving errors can occur. For example, an early stage AV may not park exactly between the markings of a parking place or not be able to detect an incident on the road early enough, or an AV may misinterpret the road markings or suffer from errors in map information.

Transitions from AD to driver refers to the situations when the driver is required or chooses to take back control of the driving task. This may have implications for the traffic flow, e.g. the vehicle may lower its speed temporarily until the driver is in the loop. *Frequency of harsh braking* can increase or decrease with AV compared to manual driving, largely depending on AV capabilities to perceive certain events such as stopped vehicles downstream early enough. This is closely related to *Frequency of shockwaves*, which may change depending on AV capabilities and on the traffic situation. *Limited/extended visibility* of AVs compared to manual vehicles refers to the sensor systems implemented in the AV and the visibility (detection of objects and the interpretation of the situation) they provide to the vehicle or driver when compared to the human capabilities in detecting the situation without technical support. This includes for example how well the immediate surroundings of the car are perceived, at which distances and in which angles the sensors work, and how reliably they provide information in different conditions (weather conditions, in case of an obstacle etc.). *False/better anticipation of intentions* is related to interpretation of information received by any sensors, AV vs. human. AVs (technology) may not be equally good as a human actor (the driver) in perceiving and interpreting all weak signals, or at the least AVs may not be capable of covering the huge variety of situations in road traffic. Specifically, this can be seen in anticipating the intentions of other road users, pedestrians and cyclists in particular. On the other hand, AVs do not get fatigued or focus on other activities than driving.

9.1.2.6 Behaviour and skills

The topic 'behaviour and skills' is largely related to the personal mobility behaviour of individual users (and non-users) and the skills required for that. With the introduction of AVs, the daily mobility choices of the AV users may change in terms of *Number of journeys* made, choice of *Destinations*, *Transport mode selection*, *Timing of journeys* and *Route selection*.

For example, automated valet parking may lead to driving more by car into the city centre instead of using public transport, as finding a parking space is often difficult in city centres (and some people do not like to park in narrow parking garages etc.), highlighted in busy hours. If car travel is more convenient, more people may choose to use a car instead of public transport or active modes. In partial automation, route choices may change e.g. to favour longer routes to travel on motorways and take use of a motorway pilot function.

Harm by delays describes the perceived harm by travellers resulting from delays in traffic, addressing both emotional and practical aspects. This may change with AD, for example some delays may be considered less harmful if the time spent in the car can be used in productive ways, reflected in the value of time.

Behavioural adaptation of non-AVs may occur if the drivers of manually driven vehicles start to copy driving behaviour of AVs, for example by using smaller or larger headways or by strictly obeying the speed limits. Behavioural adaptation may also apply to VRUs who start trusting that all vehicles will stop for them, if AVs are likely to do so, and may change their behaviour e.g. when crossing roads.

Driving skills may be affected when ADF are mature enough to take over a large part of the driving.

Driving skills refer not only to manoeuvring the vehicle at the operational level but also to higher-level skills such as focusing attention to the relevant, anticipating driving situations, interacting efficiently and safety with the other road users etc. It is expected that ADFs will at least in the short-term work only in good conditions. Therefore, drivers need to drive themselves in bad conditions, which have a higher accident risk, especially when accompanied with less driving experience overall. (This may lead also to personal mobility impacts, e.g. less travel or less car travel during adverse conditions.)

9.1.3 Impacts on transport system (*Block 3*)

9.1.3.1 Safety

Safety of road transport is defined indirectly in terms of *Number of crashes* and *Severity of crashes* for travelling (exposure) in road transport. A source of data are the public statistics in which severity can be found in four categories: fatal crashes, severe injury crashes, injury crashes, and property damages only (not, however, in all statistics). In addition, simulations and conflict techniques can be used to assess changes to traffic safety with AV.

9.1.3.2 Efficiency

Network *efficiency* refers to lane, link and intersection capacity and throughput in a regional transport network. Efficiency also refers to travel time (as part of the 'Personal mobility': Duration of journeys) and travel time reliability (Innamaa and Kuisma 2018).
Road c*apacity* can be measured as the maximum throughput which is the number of vehicles per hour through a particular road section or intersection approach, normalized to number of lanes and proportion of green time (where relevant) (Innamaa and Kuisma 2018).
Peak period travel time along a route is discussed separately because during these hours, even a small reduction of capacity would have severe impacts in the areas where peak hour traffic exceeds the capacity already in the current situation.

9.1.3.3 Infrastructure

Automated vehicles can be connected to the *Infrastructure (V2I)* and thereby receive information collected by infrastructure based systems, and be able to utilize it. *Quality of road surface*, including road markings and road maintenance, is critical for automated vehicles as localisation can be based at least partly on road markings, and the AVs may have difficulties to detect damages on the road surface such as potholes. If all AVs position themselves strictly to the position of the lane, the quality of the road surface may suffer sooner than for manual driven fleet. *Use of hard shoulders* becomes important in high level of automation when hard shoulders may be needed as safety harbours in case of malfunctioning of the AV (as part of the minimal risk manoeuvring). If hard shoulders are dedicated to being the safety harbour for the stopped AVs, then they cannot be used as temporary lane.

9.1.3.4 Environment

Impacts on the *Environment* include both tailpipe *Emissions* and greenhouse gases (CO2, NOX, CO, PM10, PM2.5, VOC emissions in total per year and per vehicle-km or mile) and the *Energy use* or consumption of the vehicle. The direct energy/emissions impacts come from the change in the driving cycle. Energy consumption can be analysed by vehicle km travelled (vehicle fleet) or by person km travelled. Changes in vehicle propulsion (e.g., electric vehicles) may also have a significant effect on tailpipe emissions. Noise can be measured as the annual average of the proportion of time when the noise level is above a certain threshold (Innamaa and Kuisma 2018). In addition to the amount of emissions, also the environment where they are produced is of importance.
Material use refers to all other material than moving power such as components needed to build AVs.

9.1.3.5 Travel behaviour / Mobility / Personal mobility

A traveller may respond to new transport options, such as AV, by changing their *travel behaviour*. The *Share of transport modes* may change in road transport or in the whole transport system (affecting multimodality). There may be more or fewer trips affecting the *Total number of journeys* (per week, in total and per inhabitant) or changes in the *Duration* (in total and per inhabitant) and in *Length of journeys* (the total kilometres or miles travelled per week in a region).

9.1.3.6 Land use

The *Need for parking slots* refers to different types of spaces needed for parking, such as the need for underground parking (m^2) and the space needed for street parking in city centre areas (m^2). For example, the use of private cars, car sharing, features and AV functionalities and urban policy affect the amount of space needed (Rämä et al. 2018).

Automated driving may increase the share of car trips out of all travelling. Due to its convenience and lower value of time, it may lead to an increase in urban sprawl and thereby affect the *Density of housing*. Planning and construction policy and offering of public transport services are means to influence density of housing.

Location of employment refers to distance of employment in relation to the city centre and major housing areas (km on average). Use of AD in commuting and willingness of employees to commute longer trips have influence on land use. Also the requirements that AVs have for parking can influence the location of the employment.

9.1.4 Impacts on societal quality of life (*Block 4*)

9.1.4.1 Public health

Morbidity refers to diseases or disabilities and takes into account the duration of the disease; it can be weighted by severity. *Mortality* is a measure for years of life lost and potential years of life lost. Road traffic can affect mortality and morbidity indirectly for example by increasing pollution and particles in the air and by influencing physical activity of citizens (the share of active transport modes), or directly through road crashes causing injuries and deaths.

9.1.4.2 Individual Quality of life

Individual Quality of life (QoL) refers to both the quantity and quality of life lived. It is accomplished as the outcome of *Social, Physical, Mental* and *Economic wellbeing.* QoL assumes that health is a function of length of life and quality of life; overall life expectancy by the amount of time lived in less than perfect health. Physical and mental wellbeing are directly linked to health; social and economic wellbeing are more indirectly linked to health but are also as such important indicators of QoL.

9.1.4.3 Equity

Equity means that all citizens have equal access to road transport services independent of road user type, *social* or *economic* background, car ownership or *region* they live in. In an optimal situation accessibility can be provided for all potential road users on a reasonable level between any desired locations.

9.2 Annex 2 – Illustrative example

The mechanisms affected by IoT (results of *Step 2* of the method) for the box *Behaviour and skills* for all AD modes are shown in Figure 26. For mechanisms coloured in orange, IoT is expected to have a direct impact when compared to the baseline, whereas for the mechanisms outlined in orange the impact is assumed to be more indirect.

For the example of Automated valet parking (AVP), when compared to the baseline (automated parking with user supervision, user needs to assign free parking space), IoT is expected to have direct impacts on *destinations* of journeys, *transport mode selection*, *timing of journeys* and *route selection*, and secondary or less direct impacts on the *number of journeys* and *driving skills*. These changes then have implications for the three impact areas (in *Step 3*): The first five impact all three areas (mobility, safety and efficiency and environment), while *Driving skills* is relevant only for traffic safety. On the other hand, the AD mode Highway Pilot – Hazard warning is expected to only have minor impacts to *Harm by delays* when compared to the baseline of non-connected automated driving, due to the limited scope of the function.

From the results of the data collection (done in *Step 4*), it was then concluded in *Step 5* that AVP may lead to a mode shift favouring the personal car and may increase the number of trips made by car. This is likely to have a negative impact on traffic safety. On the other hand, AVP decreases the amount of driving looking for a parking space, therefore decreasing exposure to traffic, which leads to a positive impact on traffic safety. These mechanisms work in opposite directions, and more information is needed on demand of AVP in order to determine, which impact will be larger.

For efficiency and environmental impacts of AVP, the results are similar. Traffic flow and emissions can be improved from removing the need to search for a parking space, but this impact can be offset by an increased number of vehicles driving into city centres due to the AVP service making it more convenient. Regarding personal mobility, increased accessibility in terms of reaching destinations is considered positive.

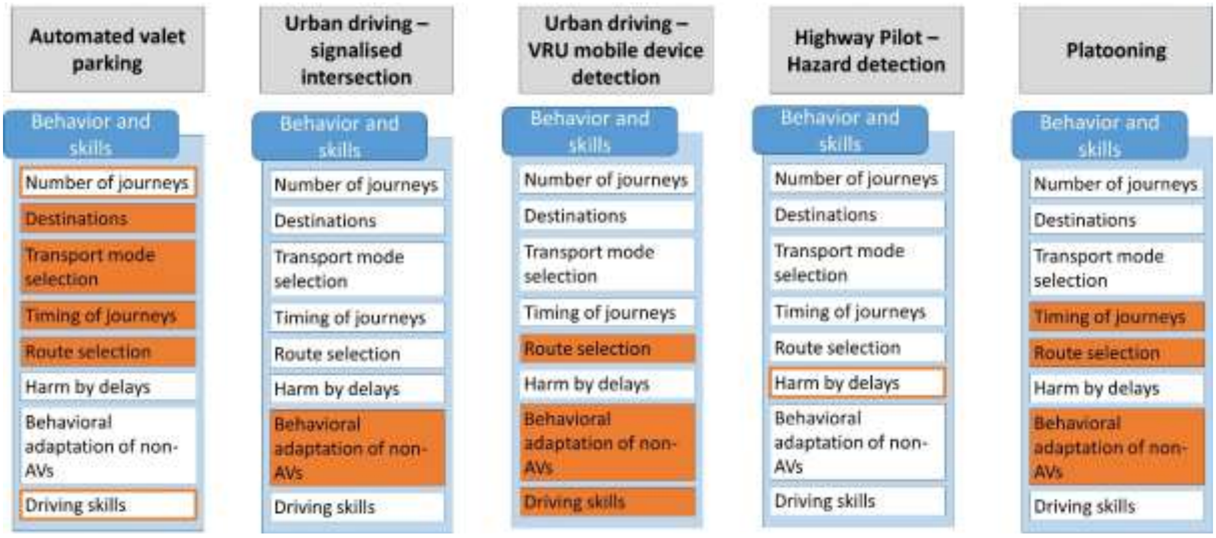


Figure 26 – Illustration of mechanisms directly (orange background) and indirectly (orange outline) impacted by IoT for each AD mode when compared to the baseline of non-connected automated driving

Results for the remaining five boxes in *Block 2* were defined in a similar way. In the last step (*Step 6*), overall potential impact mechanisms on the quality of life (health, well-being and equity) were then deduced. For example, AVP can lead to increase in social well-being due to increased accessibility of locations, but on the other hand lead to decrease in physical well-being if active travel modes such as walking and cycling are replaced by personal car use.