Enhance driver behaviour & Public Acceptance
of Connected & Autonomous vehicles

Grant agreement no.: 815098

D7.2 – Impact indicators

Date of publication: [31-01-2020]

Disclaimer

This report is part of a project that has received funding by the European Union's Horizon 2020 research and innovation programme under grant agreement number 815098.

D7.2 – Impact indicators			
Work package No.	7	**Work package Title**	Impact Assessment
Tasks involved in the reported results	- T7.2		
Deliverable owner	UMAN		
Dissemination level	[PU/PP/RE/CO]		
Due date	31.01.2020		
Delivery date	31-01-2020		

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Version History

Version	Date	Summary of changes
01	Dec 02 19	First draft table containing impact areas, indicator examples for all sections
02	Dec 09 19	Extended and updated draft table of indicator examples for all sections
03	Dec 17 19	Draft user-centric acceptance indicators as example draft for other contributors
04	Jan 06	Final draft user-centric acceptance indicators, template for all sections
05	Jan 15	Integration of reviewed user-centric acceptance, reviewed road co-users, reviewed vulnerable user groups
06	Jan 20	Integration of human factors & stakeholders
07	Jan 22	Integration of society level indicators
08	Jan 27	Review by ETELETÄR & LIST
09	Jan 30	Integration of comments LuxM
10	Jan 31	Final version

List of acronyms

Acronym	Meaning
CAV	Connected and Autonomous Vehicles
AV	Autonomous Vehicles
WTP	Willingness to Pay

Notice

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Executive summary

The goal of WP7 is to assess the long-term impact of connected- and autonomous vehicles-related solutions developed in PAsCAL and to contribute to the structure of the Guide2Autonomy. D7.2 in this context provides an overview over indicators and methodologies that can be employed both within PAsCAL as well as beyond.

The document lists indicators that will measure progress in a variety of contexts and settings, across a variety of solutions and maturity levels. Primarily, CAV user-related acceptance indicators will be covered, strongly interrelated to the document structure in D7.1, where “willingness to use/adopt”, “willingness to pay”, “willingness to let others use” as well as “changes in mobility patterns” were concepts discussed for the main framework. These are supported by indicators targeting factors such as “perceived risk”, “perceived ease of use”, “perceived quality of travel”, “perceived usefulness”, general attitudes and ergonomic and human factors.

Beyond these, acceptance by road co-users such as pedestrians and bicyclists are discussed, and acceptance by other stakeholders such as local authorities, business and producers. A particular focus is laid on the needs and requirements of vulnerable user groups, and how their perspectives can be taken into consideration, including the availability of solutions to them, their adequacy in the context, accessibility and affordability, as well as social inclusion and of course human dignity and ethics.

Finally, the document takes a higher-level abstract perspective and considers indicators that should be measured for a society wide standpoint, such as changes in overall journey times, network capacity, transport mode shifts, impacts on safety and security overall, socio-economic impacts, indicators for quality of life and public awareness, and the overall concept of public acceptance.

A wide range of academic and grey literature as well as previous EU grant-supported projects are taken into consideration to collect this overview of indicators, and where little previous research exists, new indicators are developed within PAsCAL.

1 Introduction

1.1 Purpose and organisation of the document

The following document, D7.2, aims to provide an overview over indicators and methodologies that can be employed within the PAsCAL project. It will allow to gather insights into the impact of interventions as well as help data collection on a variety of impact areas related to connected and autonomous vehicles (CAVs), the user perspective and wider societal interests. Following the identified impact areas identified in D7.1, this deliverable provides an indicator-based impact assessment framework for PAsCAL simulations, experiments, trials and pilots.

In this sense, it aids in the overall WP7 goal, which is to assess the long-term impact of the developed solutions. It is intended also to contribute to the structure of the Guide2Autonomy.

In line with Task 7.2, the document takes into account the evaluation of a range of solutions (such as personal vehicles, shared transport options, emergency vehicles) and to provide a set of impact indicators. Those solutions are considered at various levels of autonomy, connectivity, scale and maturity. Likewise, the possible involvement of various types of drivers is taken into consideration. A multi-disciplinary approach is taken, with the basis of the document formed by an in-depth review of the academic literature, grey literature and insights from corporate studies to provide the complete picture.

Following the Introduction (chapter 1), the document is divided into three thematic focus areas: user-centered acceptance indicators, vulnerable group-centered acceptance,usability indicators, and indicators that concern autonomous vehicles from a societal perspective. In line with the PAsCAL objectives the evaluation will also consider road co-users in an encounter with a CAV and other relevant stakeholders (municipalities, business, CAV operators).

In chapter 2, we will focus on indicators for CAV acceptance by users of such mobility options, meaning drivers/passengers. This section is the most extensive and in-depth one, as its goal is to provide many varied indicators directly to be adopted in the frame of the PAsCAL simulations, experiments and pilots.

In chapter 3 we will briefly summarise literature of receptivity towards autonomous vehicles by road co-users such as pedestrians and cyclists, and relevant indicators that exist to measure acceptance of CAVs from their perspective.

In chapter 4, we cover indicators that align with the perspective of vulnerable user groups, with a focus on the mobility-impaired user groups.

In chapter 5, the societal perspective is taken – impact indicators that measure the impact of autonomous vehicles on society are discussed and presented. This section is meant to provide the means for dissecting wider and broader impacts of PAsCAL, such as mobility in general, quality of life, future urban transport planning, business potential, job creation, aging society and more.

Finally, chapter 6 discusses indicators that measure the willingness of other stakeholders to accept autonomous vehicles, including the perspective of government representatives, corporate actors and others.

The document finishes with a summary and conclusion section, chapter 7. References and literature are provided in chapter 8.

The purpose of this document is also to give a first idea on how these indicators can be used by other work packages of the PAsCAL project to assess the results of laboratory and experimental trials and simulation studies from a user perspective taking into account the “pyramid of user needs” (see D7.1). For this purpose, each section includes a brief discussion of how the indicators can be used for a variety of data collection methodologies.

1.2 Intended audience of this document

The main audience for this document are the consortium members of the PAsCAL project, specifically partners responsible for the different CAV trials, simulations, pilots, survey development CAV training skills and development of business cases. The idea is to give them an overview over possible methodologies and items with which they can achieve their set goals, and to measure, evaluate and assess data in such a manner that it is cohesive across the project. The main objective of the PAsCAL project is to move the focus towards a more user-centric design of CAV research projects through the inclusion of human and societal indicators.

A secondary but no less important audience, the wider research community is invited to use the overview gained in this document to use, extend, develop and recreate impact indicators that helps gain a better understanding of acceptance of CAVs. In particular, the chapter on vulnerable user groups and accessibility measures might bring a new dimension to research being currently undertaken and make the field more inclusive.

2 Indicators of acceptance by end users

Connected and autonomous vehicles (CAVs) operate at different levels up to level 5, where, upon command, i.e. they are self-driving, and driverless. They resort to computerised systems that allow them to control acceleration and steering by collecting information about their environment. Theoretically, they could do this independently from human interaction. However, in reality humans will never be completely removed from the equation: as passengers and vehicle occupants, road co-users, stakeholders and producers of both mechanical as well as software components for the vehicles, as well as directly impacted by the consequences of introduction on a societal level, humans will always play a major role in mobility.

While autonomy is not completely new, the introduction of autonomous vehicles on public roads would be vastly different from already well-established and accepted examples: the SkyTrain in Vancouver which began operation in 1985, the DLR in London, which opened in 1987, and the Yurikamome in Tokyo, which has been running since 1995, are fully autonomous vehicles (rail systems in these cases) about which the majority of respondents on a survey, when asked about their perception, expressed no major worries (Fraszczyk, Brown, & Duan, 2015).

However, autonomous cars will be driving together with other vehicles on public roads, along with potential obstacles, perpetual environmental changes, and exposed to human decision-making and complex social interactions. An overview over the measures and impact indicators that should be considered for the acceptance of autonomous vehicles for these circumstances is the goal of the following sections.

Chapter 2 in particular will focus on end-users, i.e. the persons that will be sitting inside the vehicles at the time of driving, may it be as drivers, or passengers; and in addition, the persons that are caretakers of others that might be using these vehicles.

Each section will also have a data collection subsection attached to it; here, the possibility of collecting data across a variety of methods in the PAsCAL project will be indicated. Included are the possibility to collect data in:

- a representative survey, i.e. a large-scale survey that attempts to collect demographically stratified samples;
- observational studies, where participants interact in their normal environment without specific interventions and their behaviour is

observed, such as if an autonomous bus was sent to a regular bus station and potential customers could be observed in their reactions to it;

- experimental trials, i.e. where participants are invited to take part in a trial that includes some form of intervention and usually randomized appointment to control and experimental groups;
- laboratory trials, i.e. studies that can be observational or experimental, but are carried out in control environment, such as with a VR simulator or a home driving system; and
- computer simulations, in which existing data and mathematical models are used to reproduce an environment using a computer.

All these might be carried out throughout the PAsCAL project, and therefore, it is indicated in each section whether the conceptual area and the included indicators could potentially be employed for such methodologies within the project.

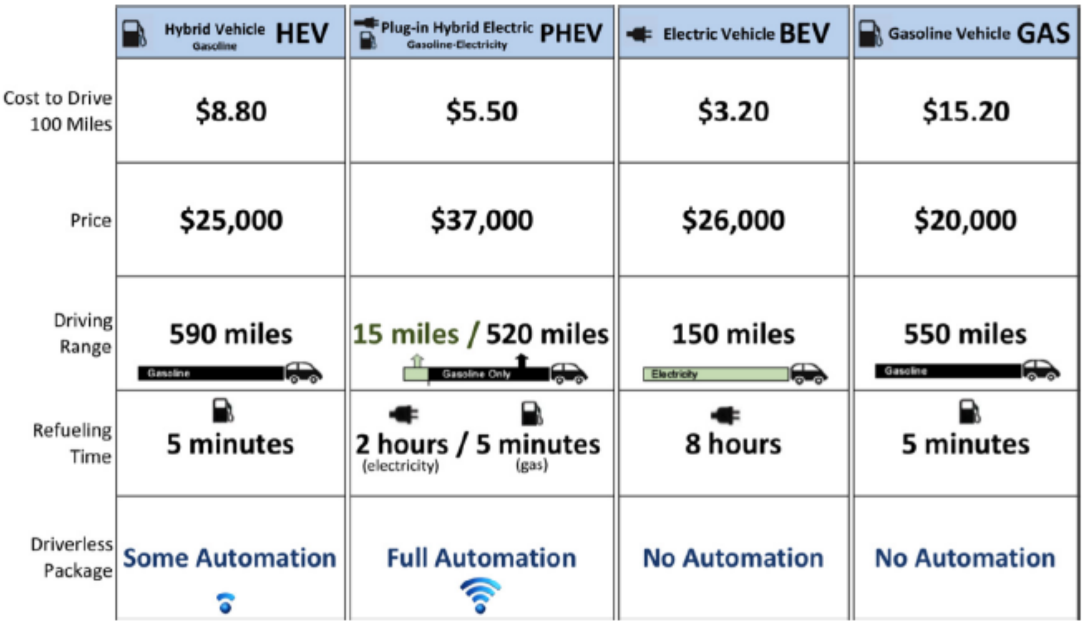
2.1 Willingness to Pay

2.1.1 General concept indicators

Willingness to pay (WTP) is generally used to describe the maximum amount an individual is willing to hand over to procure a product or service. Approaches to measuring WTP range across differential conceptual foundations and methodological implications, including market data analyses, lab and field experiments, direct and indirect surveys such as conjoint or discrete choice analyses (Breidert, Hahsler, & Reutterer, 2015).

In CAV literature, surveys are usually employed to gauge willingness to pay. Usually, items include some form of maximum price for either the inclusion of a feature, or per distance or a time metric, such as 1 Euro per km or per 5 mins.

In some situations, it might be the best option to offer a choice experiment, such as done by Daziano, Sarrias, & Leard (2017), see Figure 1. In this case, participants are offered a variety of options to choose from, including automation and no automation, crossed with a variety of payment structures, such as cost to drive and vehicle price.



	Hybrid Vehicle Gasoline **HEV**	Plug-in Hybrid Electric Gasoline-Electricity **PHEV**	Electric Vehicle **BEV**	Gasoline Vehicle **GAS**
Cost to Drive 100 Miles	$8.80	$5.50	$3.20	$15.20
Price	$25,000	$37,000	$26,000	$20,000
Driving Range	590 miles Gasoline	15 miles / 520 miles Gasoline Only	150 miles Electricity	550 miles Gasoline
Refueling Time	5 minutes	2 hours / 5 minutes (electricity) (gas)	8 hours	5 minutes
Driverless Package	Some Automation	Full Automation	No Automation	No Automation

Figure 1: Choice experimental design (Daziano et al., 2017)

Another example how one could measure WTP is given in a survey by (Schoettle & Sivak, 2014b), see Figure 2, in which participants are asked how much extra they would be willing to pay to have Level 4 autonomy technology available.

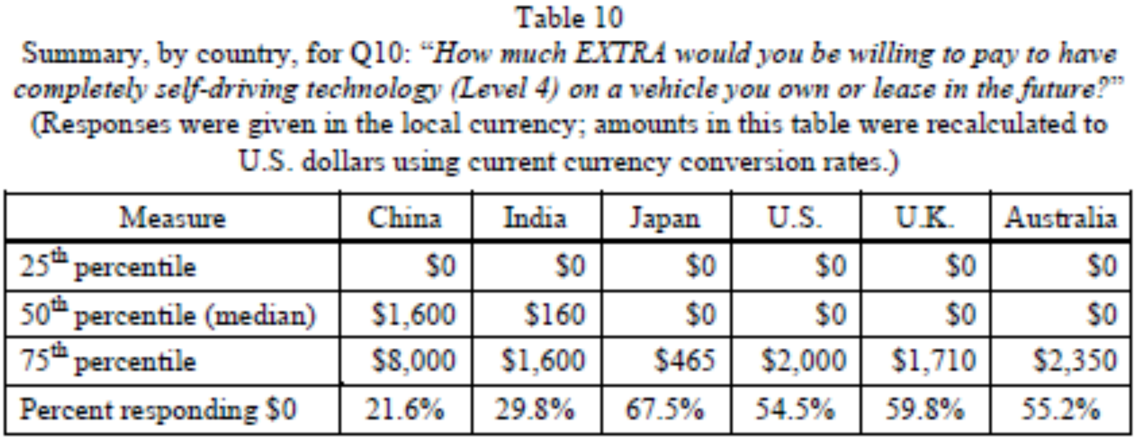


Table 10
Summary, by country, for Q10: "*How much EXTRA would you be willing to pay to have completely self-driving technology (Level 4) on a vehicle you own or lease in the future?*"
(Responses were given in the local currency; amounts in this table were recalculated to U.S. dollars using current currency conversion rates.)

Measure	China	India	Japan	U.S.	U.K.	Australia
25th percentile	$0	$0	$0	$0	$0	$0
50th percentile (median)	$1,600	$160	$0	$0	$0	$0
75th percentile	$8,000	$1,600	$465	$2,000	$1,710	$2,350
Percent responding $0	21.6%	29.8%	67.5%	54.5%	59.8%	55.2%

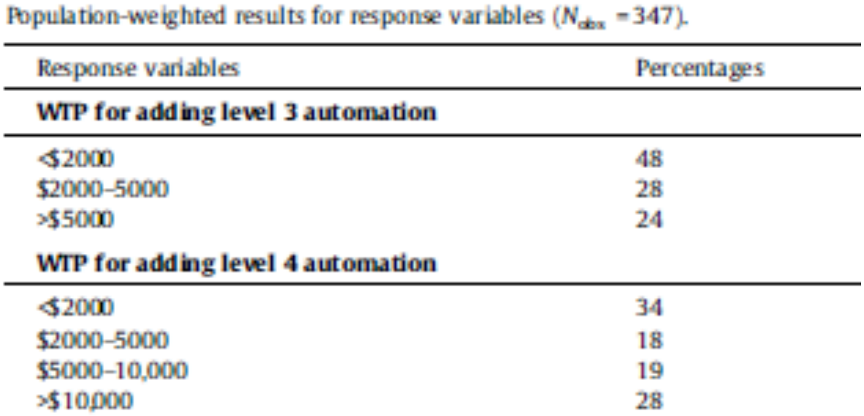
Figure 2: Willingness to pay (Schoettle & Sivak, 2014b)

This option would also be available to ask taxpayers about their willingness to pay extra taxes for technology in public transport, or about their willingness to pay extra for public transport tickets or when charged for the use of rental CAVs.

2.1.2 Solutions specific indicators

Measuring WTP is possible for a variety of different CAV solutions, and items and measurement tools for these solutions should be adapted more specifically to fit their targets.

For owned vehicles, asking users how much they would be willing to pay in terms of additional costs for Level 3, Level 4 and Level 5 automation technology in their cars is one option (Bansal, Kockelman, & Singh, 2016). An example for this kind of metric is provided in Figure 3.



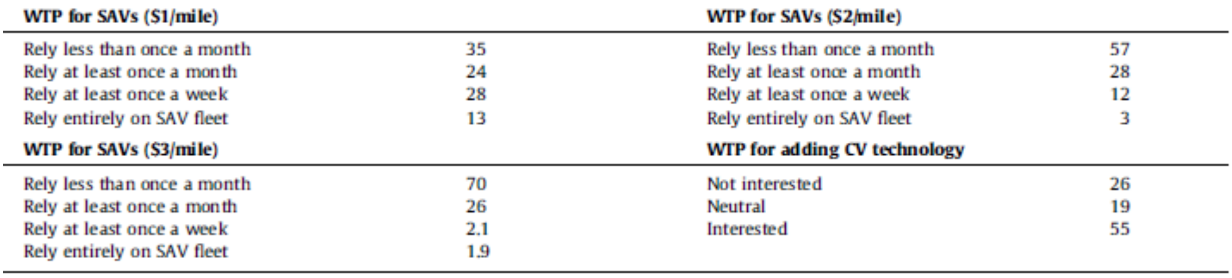
Population-weighted results for response variables (N_{obs} = 347).

Response variables	Percentages
WTP for adding level 3 automation	
<$2000	48
$2000–5000	28
>$5000	24
WTP for adding level 4 automation	
<$2000	34
$2000–5000	18
$5000–10,000	19
>$10,000	28

Figure 3: WTP for different automation levels (Bansal et al., 2016)

Other measures could include items such as “How much would you expect a fully automated driving system for your car to cost beyond the car’s original price?” and “How much money would you be willing to spend to have an autonomous driving system installed in your next car?” (Casley, Jardim, & Quartulli, 2013)

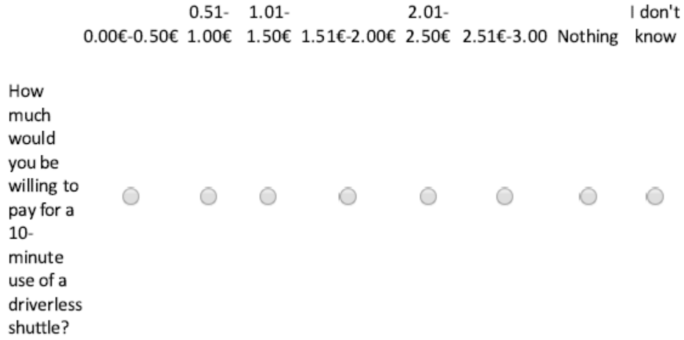
In comparison, for all types of shared vehicles, one can measure how often participants would rely on shared CAVs if those were available for various prices, see Figure 4 (Bansal et al., 2016).



WTP for SAVs ($1/mile)		WTP for SAVs ($2/mile)	
Rely less than once a month	35	Rely less than once a month	57
Rely at least once a month	24	Rely at least once a month	28
Rely at least once a week	28	Rely at least once a week	12
Rely entirely on SAV fleet	13	Rely entirely on SAV fleet	3
WTP for SAVs ($3/mile)		**WTP for adding CV technology**	
Rely less than once a month	70	Not interested	26
Rely at least once a month	26	Neutral	19
Rely at least once a week	2.1	Interested	55
Rely entirely on SAV fleet	1.9		

Figure 4: WTP for shared vehicles based on reliance (Bansal et al., 2016)

Finally, one can measure WTP for all types of shuttles or public transport options in Euro/km or Euro/min for the usage, such as currently employed by UBER or Lyft, or ask for the ticketing price that would be acceptable in comparison to today's ticket prices for public transport. One example can be found in Figure 5.



	0.00€-0.50€	0.51-1.00€	1.01-1.50€	1.51€-2.00€	2.01-2.50€	2.51€-3.00	Nothing	I don't know
How much would you be willing to pay for a 10-minute use of a driverless shuttle?	○	○	○	○	○	○	○	○

Figure 5: WTP for 10 minutes with a driverless shuttle (Nordhoff, de Winter, Madigan, et al., 2018)

Measuring rental vehicles would probably be similar across other rented solutions such as a Heli-shuttle, though price ranges would differ significantly and would have to be adapted.

Finally, one more option is to ask about WTP for connectivity only; this could be particularly relevant for emergency or service vehicles; however, this would be a decision by stakeholders such as governments or funding bodies for emergency vehicles and will be covered in Section 5.

An overview over the solutions for which the indicators described here can be employed is provided in Table 1. Most items can be used by simply adapting the target for all CAV solutions. Measuring Willingness to Pay for emergency vehicles is not conceptually sensible and therefore no indicators are provided for this solution.

Table 1: Willingness to Pay - Overview over Solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles			

2.1.3 Data collection

Indicators for the measuring of WTP can be used in a variety of data collection contexts. In particular, for data collection in PAsCAL, Table 2 provides an overview over feasible inclusions.

All items listed could potentially be included in a survey to measure general public responses for example; however, it would best to select the items that best match the purpose of the survey.

In the course of experimental field trials or VR/Home driving systems, participants could be asked to pay a certain amount for riding a CAV, or be given a certain amount of money to spend on additional features for select vehicles.

Table 2: Willingness to Pay - Overview over data collection possibilities

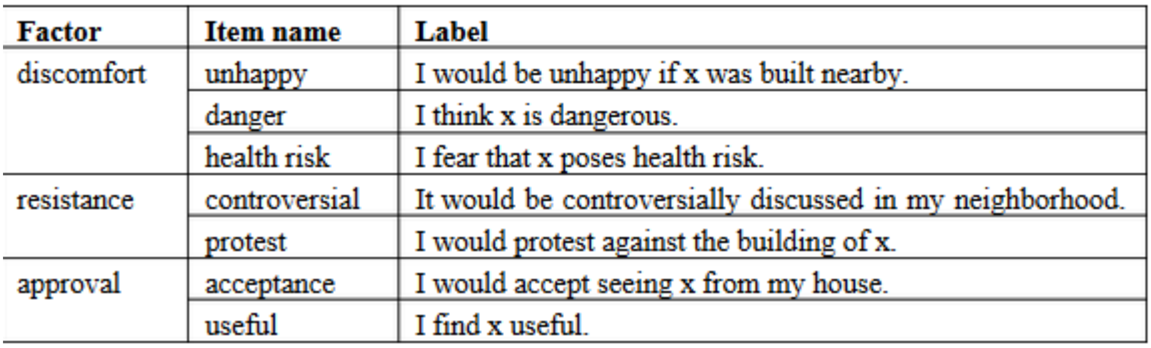
Data Collection	Representative Survey (WP3)	Observational trial (WP6)	Experimental field trial (WP6)	Lab trials (i.e. VR) (WP4)	Computational simulation (WP7)
Possible inclusion	x		x	x	

2.2 Willingness to adopt

2.2.1 General concept indicators

Willingness to adopt refers to the willingness of an individual to accept, take part in, use or at least test a product or service; short-term or long-term adoption can be distinguished here. Measures for willingness to adopt and the variables impacting it are needed to develop business models for novel technologies such as CAVs. Survey items are usually used to measure an increase or decrease in adoption or usage willingness (Bansal et al., 2016; Howard & Dai, 2014; Krueger, Rashidi, & Rose, 2016; Kyriakidis, Happee, & de Winter, 2015; Payre, Cestac, & Delhomme, 2014).

Measuring willingness to adopt or use a novel technology has often been carried out by asking participants about the affective results of the introduction or usage of the technology, as well as dangers and fears associated with those technologies (Zaunbrecher, Kowalewski, & Ziefle, 2014), for an example see Figure 6.

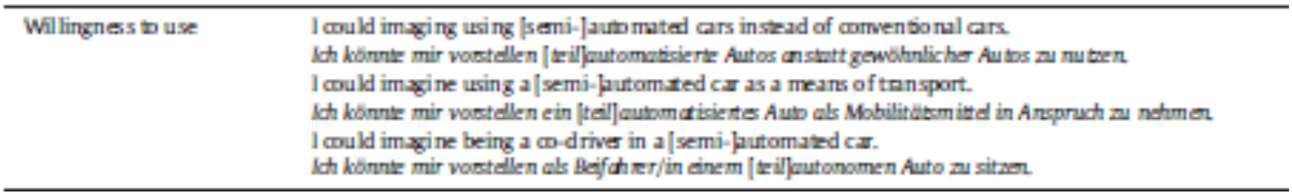


Factor	Item name	Label
discomfort	unhappy	I would be unhappy if x was built nearby.
	danger	I think x is dangerous.
	health risk	I fear that x poses health risk.
resistance	controversial	It would be controversially discussed in my neighborhood.
	protest	I would protest against the building of x.
approval	acceptance	I would accept seeing x from my house.
	useful	I find x useful.

Figure 6: Technology acceptance items (Zaunbrecher et al., 2014)

The technology acceptance model developed by (Davis, 1989) provides first ideas of factors that impact willingness to adopt, including the subareas of perceived ease of use and perceived usefulness, which will be covered in sections 2.6 and 2.8 separately.

(Bansal et al., 2016) have measured this by asking user's adoption timing, based on social prevalence of friends, with options being that a user would be willing to adopt a CAV, such as "never", "when 50 friends adopt", "when 10 friends adopt" and "as soon as available". These are solution unspecific indicators that can be adapted to different solutions as necessary. Another set of willingness to use items is provided in Figure 7.



Willingness to use	I could imaging using [semi-]automated cars instead of conventional cars.
	Ich könnte mir vorstellen [teil]automatisierte Autos anstatt gewöhnlicher Autos zu nutzen.
	I could imagine using a [semi-]automated car as a means of transport.
	Ich könnte mir vorstellen ein [teil]automatisiertes Auto als Mobilitätsmittel in Anspruch zu nehmen.
	I could imagine being a co-driver in a [semi-]automated car.
	Ich könnte mir vorstellen als Beifahrer/in einem [teil]autonomen Auto zu sitzen.

Figure 7: Willingness to use as measured for automated cars (Hohenberger, Spörrle, & Welpe, 2017)

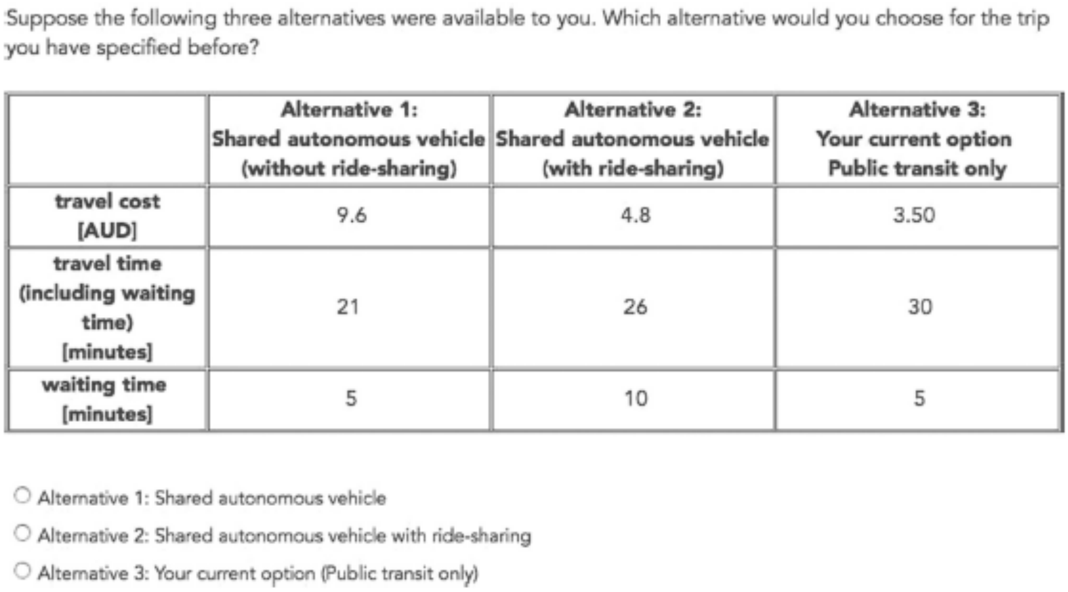
For PAsCAL purposes, based on the reviewed literature, WP3 has developed items to measure willingness to adopt/use that are also generic and can be used across all different solutions. These items are subdivided by valence, with the positive side covering one's willingness to use the solution in general if it was available, and one's liking to use the solution. The negative side covers one's attempt to avoid the solution as much as possible, active hindering of the solution and the acceptability of politicians preventing the introduction.

Finally, in terms of behavioral indicators, the willingness to use can simply be measured by the number of participants that, when confronted with the possibility of usage of a vehicle, agree to try it and then enter the vehicle to take a ride (Nordhoff, de Winter, Madigan, et al., 2018). This can be done either in a real-world field experimental trial or simulated in a VR environment.

2.2.2 Solution-specific indicators

With regards to specific solutions, one can again differ between the usage of owned vehicles and shared vehicles, though items can simply be adapted to suit the level by adding this information to the target description (Bansal et al., 2016), who asked users whether they would like to own/have a CAV and included Level 4 as a specification).

For shared CAVs, willingness to use has been measured by asking potential users to choose between different shared vehicle alternatives, for example shared CAVs with or without ride sharing vs public transport only, see Figure 8 (Krueger et al., 2016). For this kind of differentiation, prices, wait times and travel times need to be adapted to the scenario, as it would be unrealistic to present the choices independent of their consequences.



Suppose the following three alternatives were available to you. Which alternative would you choose for the trip you have specified before?

	Alternative 1: Shared autonomous vehicle (without ride-sharing)	Alternative 2: Shared autonomous vehicle (with ride-sharing)	Alternative 3: Your current option Public transit only
travel cost [AUD]	9.6	4.8	3.50
travel time (including waiting time) [minutes]	21	26	30
waiting time [minutes]	5	10	5

○ Alternative 1: Shared autonomous vehicle
○ Alternative 2: Shared autonomous vehicle with ride-sharing
○ Alternative 3: Your current option (Public transit only)

Figure 8: Alternatives for travel costs, time and waiting times suggested to participants to measure willingness to adopt (Krueger et al., 2016)

For emergency vehicles in particular, as well as for other enterprise or fleet-based mobility solutions, willingness to adopt should be considered with concepts that measure the willingness to re-educate/retrain to be able to use the solution.

An overview over the solutions for which the indicators described here can be employed is provided in Table 3. Most items can be used by simply adapting the target for all CAV solutions. Measuring Willingness to Adopt for emergency vehicles is not conceptually sensible and therefore no indicators are provided for this solution.

Table 3: Willingness to Use - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles			

2.2.3 Data collection

The indicators for the measuring of Willingness to Adopt can be employed in a variety of data collection contexts. In particular for data collection in PAsCAL, Table 4 provides an overview over feasible inclusions.

As with Willingness to Pay, feasibly all items listed could potentially be included in a survey to measure general public responses for example; however, it would best to select the items that best match the purpose of the survey.

Willingness to Adopt indicators can also be used in observational trials for data collection, for example, by counting the number of participants that actually choose to adopt a certain solution or choose to participate in a trial of CAVs out of the entire possible sample.

In the course of experimental field trials or VR/Home driving systems, participants could be asked to ride a CAV, with the intention to measure the duration of their use or the frequency of their usage if multiple participations are possible.

Table 4: Willingness to Use – Overview over data collection possibilities

Data Collection	Representative Survey (WP3)	Observational trial (WP6)	Experimental field trial (WP6)	Lab trials (i.e. VR) (WP4)	Computational simulation (WP7)
Possible inclusion	x	x	x	x	

2.3 Willingness to let others use

2.3.1 General concept indicators

This concept describes the willingness of an individual to let others that they know use this technology. The definition can be broadly inclusive of any “others”, such as friends and family, however, it usually involves the individual having decision-capabilities over another’s behaviour, such as a parent and their child, or a caretaker and their ward with a mental disability, such as a senior with dementia. This concept refers to this decision-taker allowing the other person to use the novel technology, with a distinction made whether it is used with or without their supervision. In the press, for example AVs have been discussed in the context of driving children with disabilities to their care centre (Van Ort & Scheltes, 2017) or in general having their children drive to school (Graham, 2014; Marshall, 2017), or for senior citizen who might lose their ability to drive themselves (Chapman, 2017). Indicators for a solution that measures willingness to have others use a CAV only make sense in the context of Level 5 vehicle automation across a variety of different solutions, so they will be in detail presented and discussed in the next section.

2.3.2 Solution-specific indicators

Interviews and surveys are usually employed to measure willingness to let others use, and most of the investigations previously conducted (Bansal et al., 2016; Haboucha, Ishaq, & Shiftan, 2017; Tremoulet et al., 2019) employ it for Level 5 autonomous cars, for example “How do you feel about sending an empty autonomous car to pick up your children from school?" (Haboucha et al., 2017). It is not specified whether this refers to an owned or rented car, but this could be specified when describing the target in depth to participants of the survey, for example asking "How do you feel about sending a shared shuttle to pick up your children from school?" (Wien, 2019) asks participants to answer the item "I would entrust the safety of a close relative to a self-driving vehicle" on a Likert scale.

Generally inquiring about passengers, one could also adopt an item such as "If I had passengers in my automated car, I would rather drive by myself than delegating to the automated driving system" (Payre et al., 2014).

Specifying the type of trip that one could do has also been done, for example asking whether a parent would be willing to have their children use an AV for their school trips (Bansal & Kockelman, 2017).

One study (Tremoulet et al., 2019) used an experience with a manual vs automatic car simulation to prepare children for the realities of AV driving (experimentally manipulating a system failure), after which interviews were conducted. The authors write: "All participants (parents and children) were asked whether they felt comfortable the entire ride, what the minimum age for children riding alone in AVs should be, where they imagine their children/themselves traveling to and from in AVs, whether the simulator ride was different from what they had expected—and if so how, and how they would expect to take control of an AV if necessary. Only parents were asked if they were tempted to take over control and if so when, if they would be comfortable riding in an AV with their children, and if they would be comfortable allowing their child to ride in an AV without an adult."

As a comparison, focus groups were carried out with parents who were only informed about AVs without experiencing the simulation. The following questions were reported:

- "What safety features for children would you expect AVs to have?
- What would you suggest as the minimum age for a child to ride alone in a regular taxi?
- In a driverless vehicle?
- When and where would you envision children using AVs most frequently?
- What communication features would you require for vehicles that carry children without adults (e.g., use audio or video to contact parents)?

- What sorts of AV status information would you request?”

Most items referring to this concept make sense only in Level 5 automation contexts, as in other contexts, there would always be a caretaker present that would have to drive the car anyhow.

A particular subset of items could be targeting emergency vehicles and the transport of injured or ill persons by Level 5 automated emergency vehicles. Beyond the PAsCAL demonstrations vehicles like street-cleaning or snow ploughs could also be included here in a newspaper article about emergency vehicles and autonomous technology, a trial in the UK is mentioned; the article says “The first safety feature involved an Emergency Vehicle Warning (EVW) system, which alerts drivers when an emergency vehicle is approaching and also indicates which direction it is coming from. The EVW sends a signal directly from the emergency vehicle (ambulance, fire engine, police vehicle) to nearby connected cars. The driver is then informed that the emergency vehicle is approaching and advised to make way for it.” (“SCAS joins UK’s largest autonomous and connected vehicle project,” 2018). The ability to transport seriously ill or injured patients to hospitals on blue lights with a smoother journal is mentioned as a major improvement possibility.

One study was conducted presenting participants with scenarios of how they would feel if an AV was serving them in an emergency situation instead of a regular vehicle, with the following scenarios presented:

“The first scenario included the following information: ‘You have called phone number 104 (103) asking for help because of an emergency situation. An ambulance vehicle arrived at your location to transport you to the infirmary. Traditionally configured vehicle is used where the driver sits in the cabin and a first-aid man is available in the back of the vehicle’.

The second scenario included the following information:

‘You have called phone number 104 (103) asking for help because of an emergency situation. An ambulance vehicle arrived at your location to transport you to the infirmary. The vehicle is configured as follows: the driverless ambulance is operated in autopilot mode which means that there is no driver in the cabin and 2 paramedics instead of 1 provide you treatment in the back of the vehicle’.” (Zarkeshev & Csiszár, 2019).

In this paper-simulated scenario, participants were asked to provide affect Likert scale items:

“Firstly, participants were given an ‘affect’ scale, which included the task of indicating the level of agreement or disagreement with the next assertions:

1. This scenario evokes a good feeling for me.
2. This scenario evokes a positive feeling for me.
3. This scenario evokes a favorable feeling for me.
4. This scenario evokes a cheerful feeling for me.
5. This scenario evokes a happy feeling for me.

The answers were ranged from ‘strongly disagree’ to ‘strongly agree’ according to the five-point ‘Likert’ Scale.”

Readiness to ride items were also asked:

“Secondly, respondents were provided the scale of ‘readiness to ride’, which included the task of specifying the extent of agreement or disagreement with the next assertions:

1. I am ready to ride according to this scenario.
2. I am comfortable to ride according to this scenario.
3. There is no problem for me to ride according to this scenario.
4. I am happy to ride according to this scenario.
5. I feel safe about this scenario.

The same respond options based on the ’Likert’ Scale were provided to the respondents.”

Another way to measure reactions could be to employ affective universal emotions in the way of facial expressions using imagery, such as employed in this study:

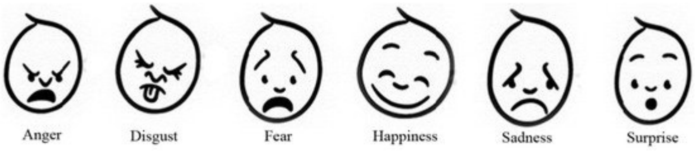


Figure 9: Facial expressions of emotions (Ekman & Friesen, 1971)

In the context of the WP3 survey, items have been developed measuring the feeling of stressfulness when one imagines other people using the solution.

Table 5: Willingness to Have Others Use - Overview over solutions showcases the solutions where these indicators are feasible to employ.

Table 5: Willingness to Have Others Use - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car			X
Rented car			X
Shared car/shuttle			X
Public transport			X
Helishuttle			X
Emergency vehicles			X

2.3.3 Data collection

The indicators for the measuring of Willingness to Let Others Use can be employed in a variety of data collection contexts. In particular for data collection in PAsCAL, Table 6 provides an overview over feasible inclusions.

All items and scenarios listed could potentially be included in a survey to measure general public responses for example; however, it would best to select the items that best match the purpose of the survey.

In the course of experimental field trials or VR/Home driving systems, participants could be asked to let their friends/family/children ride a CAV either in a simulative environment or a real CAV solution, with the intention to measure whether they agree to it or not.

Table 6: Willingness to Have Others Use - Overview over data collection possibilities

Data Collection	Representative Survey (WP3)	Observational trial (WP6)	Experimental field trial (WP6)	Lab trials (i.e. VR) (WP4)	Computational simulation (WP7)
Possible inclusion	x		x	x	

2.4 Changed mobility behaviour

2.4.1 General concept indicators

Different mobility options change users' mobility patterns, such as how often they take trips, how long those trips are, where they are going, with how many others they ride in one vehicle, and others; but also how the additional or reduced mobility affects the environment and energy consumption, which will be in more depth discussed in section 6 (Society level indicators) (Anderson et al., 2016; Greenblatt & Shaheen, 2015; Haboucha et al., 2017; Harper, Hendrickson, Mangones, & Samaras, 2016; Kyriakidis et al., 2015; Wadud, MacKenzie, & Leiby, 2016).

In this sense, perceptions about, for example, the risk inherent in, or usefulness of CAVs, could change mobility users' travel behaviours in terms of frequencies, or trip durations, distance, or the purpose of the trip taken; greater mobility demand could be one possible result (Wadud et al., 2016). This includes the willingness to use the car despite of dense traffic and traffic jams, resulting in an increase of traffic density at peak hours, also affecting time of travel. i.e. more likely to take trips at night or early hours.

Specific indicators and items will be discussed more specifically in section b), as most items regarding change mobility behaviour are solution-specific.

An impact analysis is particularly important also with an eye towards increases in individual mobility needs for vulnerable populations such as people with disabilities, senior drivers or people with medical conditions. A frequency of leaving the house can be studied as well for the general population, but it might be particularly effective to study the effect of AV introduction on changes in mobility among populations with disabilities.

Frequency of leaving the house	How many times per week do you leave the house on errands using a vehicle?
Frequency of event visits	Using a vehicle, do you visit events (such as concerts, sports events) more rarely or more frequently than last year? How many times per week do you leave the house to go to an event such as a concert or a sports event using a vehicle?
Frequency of social meetings	Using a vehicle, do you make social visits more rarely or more frequently than last year? How many times per week do you leave the house to make a social visit using a vehicle?

See Figure 10 for a first idea how such an analysis could be carried out for vehicle miles travelled for different populations (Harper et al., 2016).

Demand wedge	Age group	Male	Standard error	Female	Standard error	Total increase in VMT (billion miles)	% Increase in total VMT[c]
Demand wedge 1: Adult non-drivers[a]	19–64	0	0	0	0	154	7.20%
	65–74	0	0	0	0	18	0.80%
	75–84	0	0	0	0	15	0.70%
	85+	0	0	0	0	7	0.30%
Demand wedge 2: Elderly drivers without a medical condition	65–74	11,259	455	6,076	241	27	1.30%
	75–84	8,879	524	3,944	259	12	0.60%
	85+	4,561	509	3,752	549	7	0.30%
Demand wedge 3: Adult drivers with a medical condition[b]	19–64	8,970	706	6,184	700	31	1.40%
	65–74	6,818	945	4,306	654	12	0.60%
	75–84	5,224	1,125	1,804	198	9	0.40%
	85+	4,073	1,262	1,528	393	3	0.10%

Note: Vehicle Miles Traveled (VMT) and Vehicle Miles Driven (VMD) are equivalent for this analysis.

Figure 10: Change in mobility patterns for three different types of demand populations, from Harper et al., (2016).

2.4.2 Solution-specific indicators

The following is a table of items based on items found in previous literature (Daziano et al., 2017; Haboucha et al., 2017; Kyriakidis et al., 2015; Payre et al., 2014) and generated in the context of the WP3 survey. Example indicators (in particular solution-specific items are presented in the respective column.

Table 7: Changed Mobility behavior - solution specific indicators

General Driving Concepts	**Example indicators**
Distance of travel /time	How many kms per week do you drive with your personal car? How many kms per month do you travel by public transport? How many kms per day do you travel by shared autonomous vehicles?
Percentage of travel in AV	What percentage of your travel time in public transport do you spend in an autonomous vehicle (as opposed to a conventional vehicle with a driver)?
Nr of yearly driving license acquisition	Do you own a driving license, and if yes, what type (option)?
Nr of car registrations	Data from car register per year
Nr of public transport tickets sold	Data from public transport offices per year
Nr of season tickets sold	Data from public transport offices per year Do you own a monthly/yearly public transport ticket?
Nr of users of car sharing programmes	Data from car sharing enterprises of customers per year
Frequency of car rental in car sharing programmes	Data from car sharing enterprises of rentals per year
Parking at destination	The last ten times you used your personal vehicle to reach a destination, did you pay parking? How much on average did you pay for a parking ticket at your destination?

	The last ten times you used a shared vehicle to reach a destination, did you pay for parking?
Search for parking per ride	The last ten times you used your personal vehicle to reach a destination, many minutes did you search for parking? The last ten times you used a shared vehicle to reach a destination, many minutes did you search for parking?
Use of valet parking	The last ten times you used your personal vehicle to reach a destination, did you make use of valet parking (including the autonomous feature of your car parking itself?) The last ten times you used a shared vehicle to reach a destination, did you make use of valet parking (including the autonomous feature of your car parking itself?)
Work/Company related concepts	**Example indicators**
Trip distance to work	What is the direct distance (birds view) from your home to your workplace (one way)?
Work office days per week	Out of seven days a week, how many days do you cover the distance to work?
Vehicle to work	What mobility option do you use to get to work (foot/bike/tram/bus/train/ICE/car/motorbike/roller)
Percentage of work time spent driving	(for people that work in driving related industries) What is the percentage of your work time you spend driving (for work reasons?) How many kms do you on average cover for work reasons?
Nr of company cars registered	Data from variety of companies of vehicles registered per year

	Do you have access to a company car? How many kms on average do you drive with your company car per week?
Need to learn to drive an automated vehicle	(Level 3-4) Would your work require that you learn how to drive an automated vehicle? Would you be willing to partake in training to learn how to drive in an automated vehicle?

Table 8: Change of Mobility - Overview over solutions

CAV Solutions	**Level 3 (conditional automation)**	**Level 4 (high automation)**	**Level 5 (full automation)**
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles			

2.4.3 Data collection

The indicators for the measuring of Changed Mobility can be employed in a variety of data collection contexts. In particular for data collection in PAsCAL, Table 9 provides an overview over feasible inclusions.

All items and scenarios listed could potentially be included in a survey to measure general public responses for example; however, it would best to select the items that best match the purpose of the survey.

Observational and data from existing sources should also be employed to track changed in general society level mobility; this data could also be used to create predictive models via computational simulations and agent-based models to study potential effects of increased in travel demand and their effects on other mobility areas.

Table 9: Change of Mobility - Overview over data collection possibilities

Data Collection	Representative Survey (WP3)	Observational trial (WP6)	Experimental field trial (WP6)	Lab trials (i.e. VR) (WP4)	Computational simulation (WP7)
Possible inclusion	x	x			x

2.5 Perceived Risk

2.5.1 General concept indicators

As already described in D7.1, much literature has discussed that automated driving systems could potentially increase safety (Anderson et al., 2016) – indeed, if the technology used is faultless or cannot be externally influenced, it could have the potential to be the optimal solution in terms of safety. However, the other side is also true – CAVs could potentially be a major risk source if the software solution fails or is infiltrated from outside sources (Kyriakidis et al., 2015).

Safety and security concerns impact potential drivers' perceived risk, and form the fundament for CAV use. Without allaying concerns of future users in this regard, large-scale adoption is not feasible.

The subjective perceptions of safety and security are often subsumed under the concept of "trust" in the literature (Choi & Ji, 2015; Kaur & Rampersad, 2018; Shariff, Bonnefon, & Rahwan, 2017). One scale was developed in particular for human-machine trust based on a word-cluster analysis, and can be seen in Figure 11. Items can be answered on a Likert scale and can be used across a variety of CAV solutions, or for specific solutions when slightly reworded to match this target.

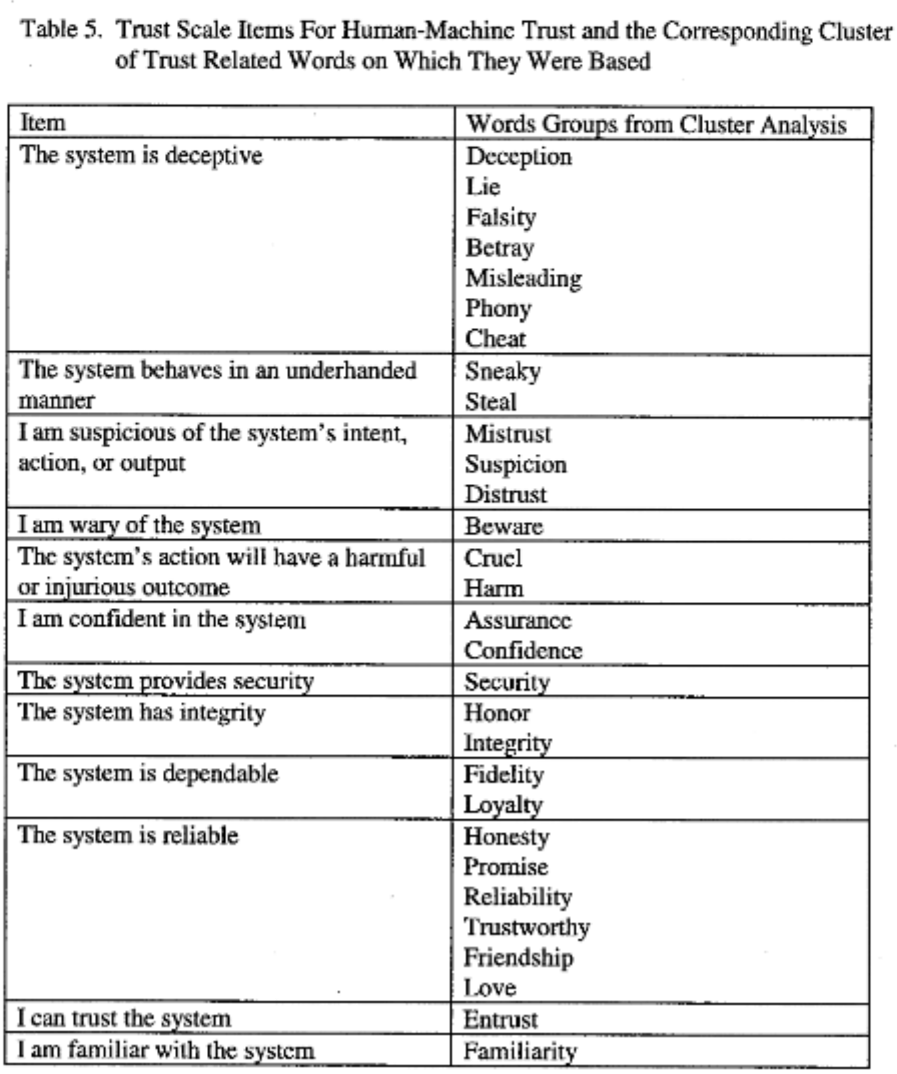


Table 5. Trust Scale Items For Human-Machine Trust and the Corresponding Cluster of Trust Related Words on Which They Were Based

Item	Words Groups from Cluster Analysis
The system is deceptive	Deception Lie Falsity Betray Misleading Phony Cheat
The system behaves in an underhanded manner	Sneaky Steal
I am suspicious of the system's intent, action, or output	Mistrust Suspicion Distrust
I am wary of the system	Beware
The system's action will have a harmful or injurious outcome	Cruel Harm
I am confident in the system	Assurance Confidence
The system provides security	Security
The system has integrity	Honor Integrity
The system is dependable	Fidelity Loyalty
The system is reliable	Honesty Promise Reliability Trustworthy Friendship Love
I can trust the system	Entrust
I am familiar with the system	Familiarity

Figure 11: Trust Scale Items for Human-Machine Trust (Jian, Bisantz, & Drury, 2000)

Risk perception varies on the cases studied and the context provided (for a review, see Kyriakidis et al., (2015)). Studies have asked participants about their risk perception regarding the reliability of vehicle functioning (Sommer, 2013), or about fear of system/equipment failure, and vehicle performance in unexpected situations (Schoettle & Sivak, 2014a, 2014b). Risk perception might also be impacted by demographics and personality of person that uses the vehicle. Perception of risk might also vary depending on whether one talks about oneself, the general public, or letting others use CAVs; this might then entail further conditions.

In a study on self-driving systems, Wien (2019) asked participants the following items with the option to answer on a Likert scale: I believe a self-driving vehicle would drive better than the average human driver. I think that the self-driving system provides me with more safety compared to manually driving.

Other items that have been used in the context of CAVs are the following:

- “A computer does not drink, it is never tired. It is always attentive. There will be fewer human errors.”
- “I would be confident in this type of shuttle.”
- “I understand that it would be safer than humans, but I have a certain apprehension.”
- “I feel safer in manual mode.”,

from a study by Distler, Lallemand, & Bellet, (2018).

Lee, Kim, Lee, & Shin (2015) proposed to measure risk perception with a scale composed of five adjectival items, namely “dangerous”, “hazardous”, “risky”, “unsafe”, and “scary”, while cognitive trust ($\alpha = .77$) was measured with the four adjectival items, i.e. “credible,” “reliable,” “accurate,” and “useful,” and affective trust ($\alpha = .86$) was assessed with the three adjectival items “likeable,” “enjoyable,” and “positive”.

Items should also consider covering asking indirectly for risk perception by targeting a person’s need for control inside a vehicle (“I would like to recover control from the automated pilot if I did not like the way it drives”, (Payre et al., 2014)).

Finally, in terms of emergency vehicles, in their study, Schoettle & Sivak, (2014a) asked about their participants feelings regarding improved emergency response to crashes when using a CAV for emergency transport for example ambulance.

Based on the above literature, in WP3 within PAsCAL multiple indicators have been developed for the survey to be conducted, including items targeting data safety and security, risk of accidents, perceived frequency of accidents, less/more dangerous travelling in general, less/more control of companies on my behavior, less/more data access of companies, lower/higher danger of terrorism, lower/higher danger of hacker attacks, higher/lower internal security (state) and lower/higher danger of intentional car damage. Most of the mentioned items can, as already mentioned, be specifically adapted to individual solutions by extending the wording or including a description of a specific target (such as an owned car or a helishuttle).

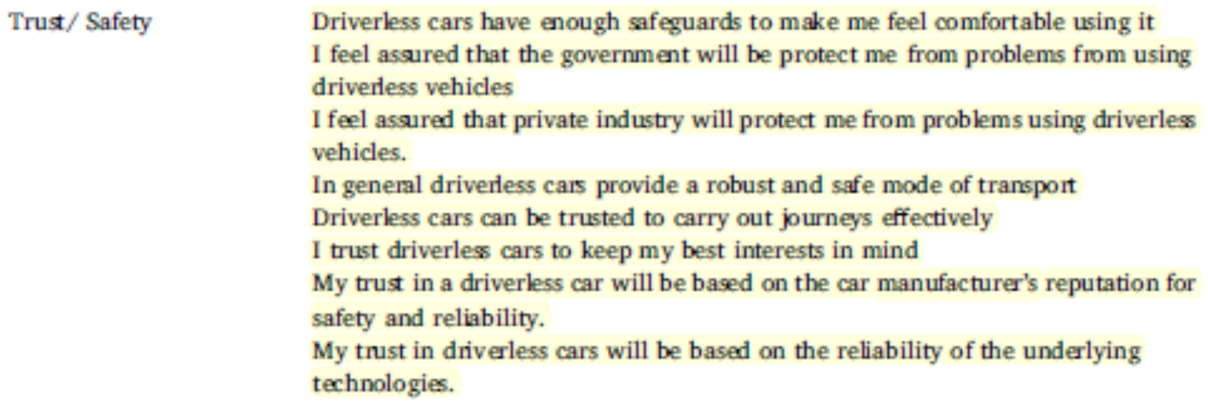
2.5.2 Solution-specific indicators

Specifically, regarding driverless shuttles, some studies have developed indicators to measure acceptance. In one study, participants were asked in an interview about their risk perception of a driverless shuttle, with many answering that they think that the self-driving bus only is safe when a steward is present (Wien, 2019).

In one study, participants experienced a drive with a CAV themselves and were afterwards asked to answer the following items on a Likert scale (Distler et al., 2018):

- “The experience reassured me with regards to safety.”
- “This shuttle drives better than I do.”
- “Before having used the shuttle, it appeared to me that safety was essential. But the shuttle gave me a rather strong feeling of security.”
- “I did not feel outstandingly safe. There are no seat belts, it might be difficult to hold on to something in case of a strong braking.”
- “One gets lost in all of the security measures: slowness, emergency stops.”

Finally, Kaur & Rampersad (2018) have developed items to cover trust and security, as follows in Figure 12.



Trust/ Safety	Driverless cars have enough safeguards to make me feel comfortable using it
	I feel assured that the government will be protect me from problems from using driverless vehicles
	I feel assured that private industry will protect me from problems using driverless vehicles.
	In general driverless cars provide a robust and safe mode of transport
	Driverless cars can be trusted to carry out journeys effectively
	I trust driverless cars to keep my best interests in mind
	My trust in a driverless car will be based on the car manufacturer’s reputation for safety and reliability.
	My trust in driverless cars will be based on the reliability of the underlying technologies.

Figure 12: Items on trust and safety (Kaur & Rampersad, 2018)

Table 10: Risk Perception - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles	x	x	x

2.5.3 Data collection

The indicators for the measuring of Perceived Risk can be employed in a variety of data collection contexts. In particular for data collection in PAsCAL, the table below provides an overview over feasible inclusions.

All items and scenarios listed could potentially be included in a survey to measure general public responses for example; however, it would best to select the items that best match the purpose of the survey. They could also be included in a survey following an observational trial with a CAV experience or a VR experience.

Table 11: Risk Perception - Overview over data collection possibilities

Data Collection	Representative Survey (WP3)	Observational trial (WP6)	Experimental field trial (WP6)	Lab trials (i.e. VR) (WP4)	Computational simulation (WP7)
Possible inclusion	x	x		x	

2.6 Perceived Ease of Use

2.6.1 General concept indicators

Ease of use can be defined as “the degree to which a person believes that using a particular system would be free from effort” based on the proposed definition by Davis (1989), as part of the technology acceptance model. Elements include how quickly a system or technology can be learned by its users, the complexity of and fit with the context in which it functions, as well as barrier perception. Therefore, a large part of perceived ease of use of CAVs is based on the application of functional design, increases in reliability, and convenience, but is also influenced by users’ self-efficacy (Bansal et al., 2016).

The most basic item based on the technology acceptance model, covering ease of use, is to ask participants via interviews, focus groups or surveys, “How easy would you find it to use the vehicle?” (Rödel, Stadler, Meschtscherjakov, & Tscheligi, 2014). In another survey study specifically targeting participants who had some experience with automation, participants were also simply asked whether driverless vehicles were easy to use (Nordhoff, de Winter, Kyriakidis, van Arem, & Happee, 2018).

Research on human-machine interaction in the context of CAV-driver interaction has been carried out and will be further discussed in section 2.10 (Human factors) (for examples, see Debernard, Chauvin, Pokam, & Langlois, 2016; Saffarian, de Winter, & Happee, 2012); however, design impacts on ease of use have seldom been investigated. In one study, participants, when interacting with an artificial driving agent, were observed for their preference on the dimensions of human appearance and intelligence.

In the context of WP3, various items for all possible solutions have been developed based on prior literature found (Bansal et al., 2016; Distler et al., 2018; Haboucha et al., 2017; Lavieri et al., 2017; Zmud & Sener, 2017). Indicators include items on convenient/inconvenient experiences while using the solution, usage experiences being relaxed/stressful, low/high self-efficacy when using the technology, and low/high problems with the usage of the solution. Additionally, items targeting comprehensibility of user interface should be included whenever a user interface is tested.

Particular items previously employed in studies to measure ease of use were "Autonomous vehicles will make my life easier since I will no longer need to look for parking" (Haboucha et al., 2017), as well as “Do drivers like the system?” “On what types of road could drivers use the system?” (Piao, Mcdonald, Henry, Vaa, & Tveit, 2005) and “Automated vehicles will make life easier.” (Wien, 2019).

2.6.2 Solution-specific indicators

In the context of shared autonomous shuttles specifically, one study used a field trial, and after users experienced a drive in a real-life autonomous shuttle, they were asked whether it had been easier to use than previously imagined (Distler et al., 2018). Another question to participants in another simulated drive trial included whether they perceived the use of already-known cars vs higher autonomy cars in any way easier or more difficult (Rödel et al., 2014). In terms of the design of the service, in a study, participants were asked for the perceived utility and ease of use for on-demand services that were included (i.e. calling a shuttle service via app) – this should also be always considered when targeting rented or shuttle solutions, as those vehicles will require application interaction that might not be necessary with an owned vehicle (Wien, 2019).

Most items in this domain can be used across all levels of automation and for all solutions, as showcased in the table below.

Table 12: Perceived Ease of Use - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles			

2.6.3 Data collection

The indicators for the measuring of Perceived Ease of Use can be employed in a variety of data collection contexts. In particular for data collection in PAsCAL, Table 13 provides an overview over feasible inclusions.

All items and scenarios listed could potentially be included in a survey to measure general public responses for example; however, it would best to select the items that best match the purpose of the survey.

Ease of Use indicators can also be used in observational trials for data collection, for example, by having an outside evaluator evaluate time and effort that it takes participants to use a CAV, or by providing surveys or interview opportunities after a scenario experience.

In the course of experimental field trials or VR/Home driving systems, participants could be asked to ride a CAV, with the intention to measure time spent figuring out the system and provide Likert scales evaluating human factors and ergonomics.

Table 13: Perceived Ease of Use - Overview over data collection possibilities

Data Collection	Representative Survey (WP3)	Observational trial (WP6)	Experimental field trial (WP6)	Lab trials (i.e. VR) (WP4)	Computational simulation (WP7)
Possible inclusion	x	x	x	x	

2.7 Perceived quality of travel

2.7.1 General concept indicators

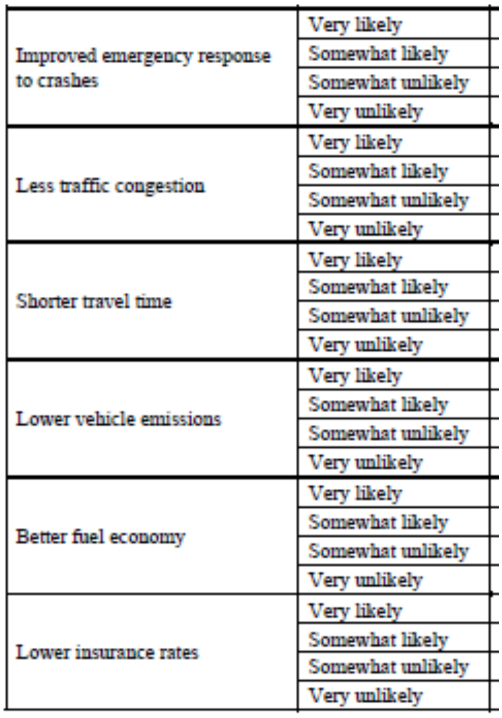
The definition for quality of travel can be adapted from the similar concept of quality of life (Costanza et al., 2008), in that it is a term for the quality of various experiences during travel; here it refers to a subjective expectation of an individual for a good travel experience, and takes into account both negative and positive features of CAV travel.

In a study of participants actually experiencing an autonomous shuttle vehicle, in the survey afterwards, the strongest rated item was found to express that “taking a ride in the shuttle was fun and enjoyable” (Nordhoff, de Winter, Madigan, et al., 2018).

Comparative items that compare comfort with one of conventional vehicles can also be employed, for example “I would feel more comfortable in a self-driving vehicle than in a regular vehicle” (Haboucha et al., 2017).

Previous literature has for example defined the temperature, rate of acceleration/deceleration, ‘jerk’ (the first derivative of acceleration), seating type, perceived personal security and crowding level, as indicators for quality of travel (Le Vine, Zolfaghari, & Polak, 2015). All of these could be adapted to check when participants in field studies for the first-time experience autonomous vehicles. Additionally, the slowness of autonomous travel and its strategic disadvantage in pedestrian interaction have been named as potential detractors of adoption (Millard-Ball, 2018), which could also be included in a questionnaire following a real-life experience of a CAV. An option could be an item such as “‘I believe that due to automated cars, we will reach our destination faster/slower” (Hohenberger et al., 2017).

In the survey by Schoettle & Sivak (2014b, 2014a), participants were asked to answer the question "How likely do you think it is that the following benefits will occur when using completely self-driving vehicles (Level 4)?", with answer options such as in Figure 12; all of these could be considered part of quality of travel indicators and could be asked for a variety of relevant CAV solutions.



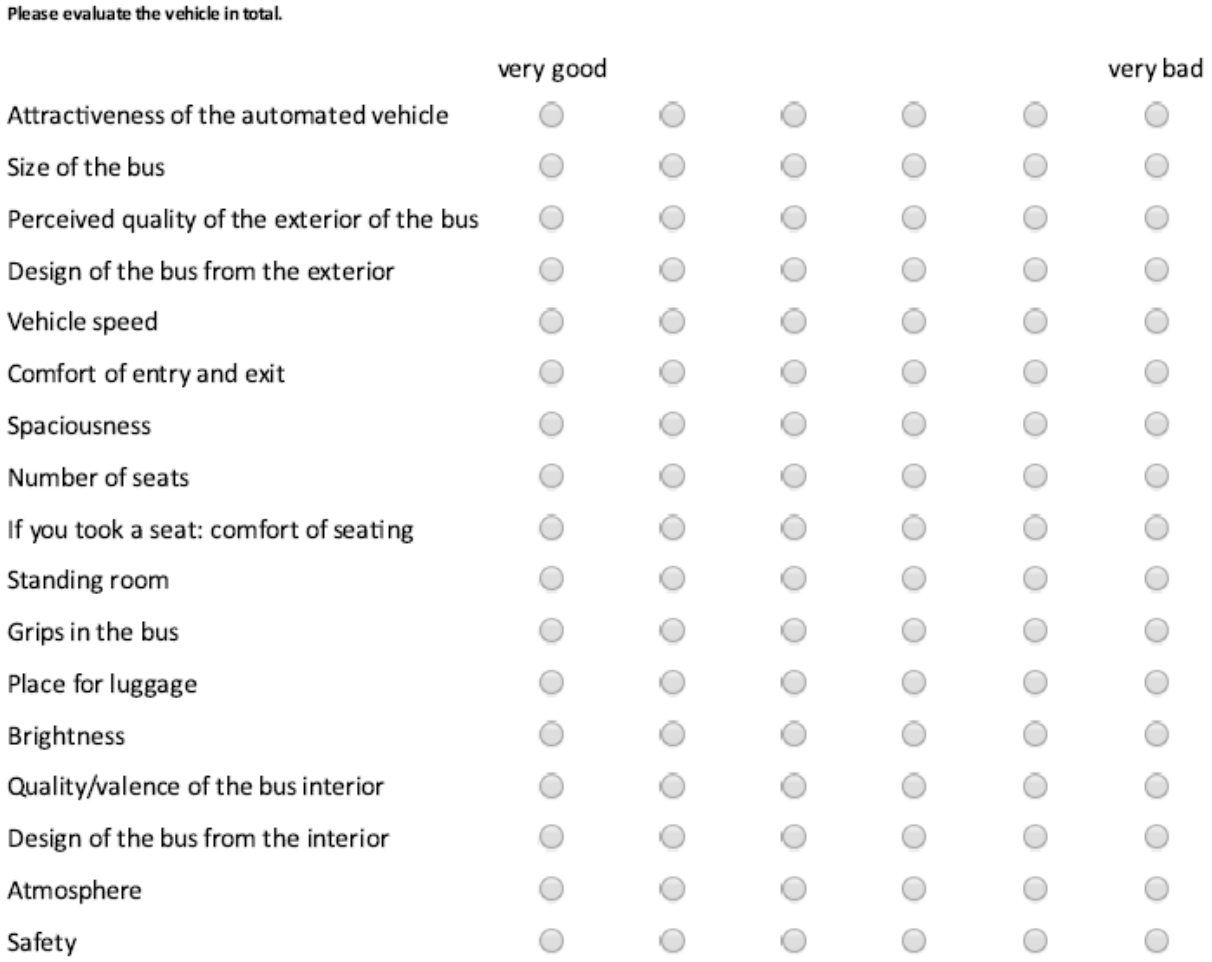
Improved emergency response to crashes	Very likely
	Somewhat likely
	Somewhat unlikely
	Very unlikely
Less traffic congestion	Very likely
	Somewhat likely
	Somewhat unlikely
	Very unlikely
Shorter travel time	Very likely
	Somewhat likely
	Somewhat unlikely
	Very unlikely
Lower vehicle emissions	Very likely
	Somewhat likely
	Somewhat unlikely
	Very unlikely
Better fuel economy	Very likely
	Somewhat likely
	Somewhat unlikely
	Very unlikely
Lower insurance rates	Very likely
	Somewhat likely
	Somewhat unlikely
	Very unlikely

Figure 12: Items regarding quality of travel as used in a survey by (Schoettle & Sivak, 2014a)

Indicators covering additional leisure time due to the introduction of CAVs have been reported in many surveys on CAVs (Haboucha et al., 2017; Howard & Dai, 2014; Schoettle & Sivak, 2014a, 2014b); for example, in one study, authors introduced items such as "It is more fun to drive an autonomous vehicle compared to a conventional car" (Haboucha et al., 2017), and questions regarding whether, if in a CAV, participants would spend their time with leisure activities or watch the road (Schoettle & Sivak, 2014a).

Additionally, items that ask participants whether using CAVs might benefit the environment, (Fagnant & Kockelman, 2014; Greenblatt & Shaheen, 2015; Haboucha et al., 2017) and impact sustainability positively (Fraedrich & Lenz, 2013) might be important to include when measuring perceived quality of travel, as higher personal identification due to value overlap on environmental and sustainability values could result in higher enjoyment and positively impact quality of travel experiences. Similar findings might exist for identification with novel technologies; therefore, items could include measuring being an early adopter and whether one’s technological interest positively impacts travel experience (Haboucha et al., 2017).

Finally, one could ask how much participants would be willing to pay more for higher quality of travel, such as done in a study by Nordhoff, de Winter, Madigan, et al., (2018). Here, following an immersive real-life experience with a CAV, participants were asked for the comfort and reliability of the shuttle on a scale from very good to very bad (6-point Likert scale), as well as for evaluation of the vehicle in total (see Figure 13).



Please evaluate the vehicle in total.

	very good					very bad
Attractiveness of the automated vehicle	○	○	○	○	○	○
Size of the bus	○	○	○	○	○	○
Perceived quality of the exterior of the bus	○	○	○	○	○	○
Design of the bus from the exterior	○	○	○	○	○	○
Vehicle speed	○	○	○	○	○	○
Comfort of entry and exit	○	○	○	○	○	○
Spaciousness	○	○	○	○	○	○
Number of seats	○	○	○	○	○	○
If you took a seat: comfort of seating	○	○	○	○	○	○
Standing room	○	○	○	○	○	○
Grips in the bus	○	○	○	○	○	○
Place for luggage	○	○	○	○	○	○
Brightness	○	○	○	○	○	○
Quality/valence of the bus interior	○	○	○	○	○	○
Design of the bus from the interior	○	○	○	○	○	○
Atmosphere	○	○	○	○	○	○
Safety	○	○	○	○	○	○

Figure 13: Vehicle evaluation measures (Nordhoff, de Winter, Madigan, et al., 2018)

Participants were also presented with the following items regarding quality of travel:

- “Taking a ride in the driverless shuttle was fun and enjoyable.”
- “I find the trip in the driverless shuttle boring.”
- “The driverless shuttle is more efficient/faster than my existing form of travel.”
- “I felt safe in the driverless shuttle throughout the whole trip.”

In the context of WP3, based on the prior literature mentioned, some items were developed as indicators to measure perceived quality of travel, including items targeting whether CAVs are less/more fun while driving, less/more fun while travelling, whether participants would experience less/more comfort while travelling and in general whether travel would be slower/faster.

2.7.2 Solution-specific indicators

In terms of solution specific indicators, one should clearly distinguish what level of automation is present in the items used to measure this concept, as the perceived quality of travel might vary between them widely. In particular, items might have to be phrased differently depending on whether the travel includes need for attention and control or not. Here, the wording “drive” plays a large role, as for example some surveys include items such as “It is more fun to drive an autonomous vehicle compared to a conventional car” (Haboucha et al., 2017) and “How much fun would you have while driving such a car?” (Rödel et al., 2014), which implies some level of control from the side of the driver, and therefore more likely to be used in Level 3/Level 4 automation cases.

Furthermore, the presence of other passengers should be measured as an impact on comfort and quality of travel. Items such as “I would feel more comfortable in a self-driving bus with several passengers than in one with few passengers.” (Haboucha et al., 2017) could be used for this purpose, or “I dislike that I might have to share the driverless shuttle with unknown passengers.” (Nordhoff, de Winter, Madigan, et al., 2018)

Otherwise, most items mentioned can be adapted by changing the type of vehicle by referring to it as such in the target description of the survey.

Table 14: Perceived quality of travel - Overview over solutions

CAV Solutions	**Level 3 (conditional automation)**	**Level 4 (high automation)**	**Level 5 (full automation)**
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles	x	x	x

2.7.3 Data collection

The indicators for the measuring of Perceived quality of travel can be employed in a variety of data collection contexts. In particular for data collection in PAsCAL, Table 15 provides an overview over feasible inclusions.

All items and scenarios listed could potentially be included in a survey to measure general public responses for example; however, it would best to select the items that best match the purpose of the survey.

Travel quality indicators can also be used in observational trials for data collection, for example, by measuring how often or how much time participants spend in a CAV, or by providing surveys or interview opportunities after a scenario experience.

In the course of experimental field trials or VR/Home driving systems, participants could be asked to ride a CAV, with the intention to measure time spent inside the vehicle, number of repetitions cycles a participant is willing to participate in and by providing surveys to measure the quality following the experience.

Table 15: Perceived quality of travel - Overview over data collection possibilities

Data Collection	**Representative Survey (WP3)**	**Observational trial (WP6)**	**Experimental field trial (WP6)**	**Lab trials (i.e. VR) (WP4)**	**Computational simulation (WP7)**
Possible inclusion	**x**	**x**	**x**	**x**	

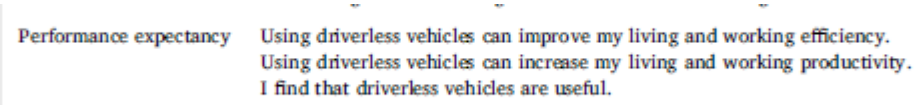
2.8 Perceived usefulness

2.8.1 General concept indicators

Perceived usefulness, adapted from the concept by (Davis, 1989), can be defined as “the degree to which a person believes that using a particular system would enhance their life, performance or goal-achievement”. It is considered to be a variable that is fundamental and influential in the decision to use technologies. In particular, relevant outcomes from the perspective of the user that have been identified in the context of usefulness have been perceived effectiveness, productivity and time savings (Davis, 1989).

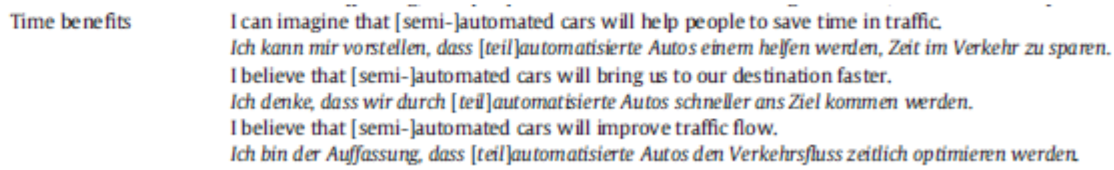
The simplest item form would be to ask participants “How useful is the solution for your daily mobility behavior?”, (Distler et al., 2018), or “I think that the [autonomous technology] is useful” (Cramer, Evers, Kemper, & Wielinga, 2008).

More specifically, convenience, efficiency and productivity are key factors for measuring overall usefulness and could be measured such as for example in Figure 14 or Figure 15.



Performance expectancy	Using driverless vehicles can improve my living and working efficiency.
	Using driverless vehicles can increase my living and working productivity.
	I find that driverless vehicles are useful.

Figure 14: Items measuring performance expectancy of driverless vehicles (Kaur & Rampersad, 2018)



Time benefits	I can imagine that [semi-]automated cars will help people to save time in traffic.
	Ich kann mir vorstellen, dass [teil]automatisierte Autos einem helfen werden, Zeit im Verkehr zu sparen.
	I believe that [semi-]automated cars will bring us to our destination faster.
	Ich denke, dass wir durch [teil]automatisierte Autos schneller ans Ziel kommen werden.
	I believe that [semi-]automated cars will improve traffic flow.
	Ich bin der Auffassung, dass [teil]automatisierte Autos den Verkehrsfluss zeitlich optimieren werden.

Figure 15: Items measuring time benefits gained by using autonomous vehicles (Hohenberger et al., 2017)

Convenience is generally used in the literature around CAVs in two ways: the addition of amenities or services that increase accessibility and decrease frustration, and those that save resources. In a survey this could be done by listing examples that increase convenience, such as an increase in last-mile services, lack of needing to find parking spots (Greenblatt & Shaheen, 2015); higher work efficiency (provisions can enable multitasking to work during trips) due to access to wi-fi and availability of real-time information applications (Shin, Bhat, You, Garikapati, & Pendyala, 2015); and reduced traffic leading to lower travel times (Roncoli, Papageorgiou, & Papamichail, 2015), or not needing to find parking spots (Howard & Dai, 2014).

Perceived usefulness can also be measured with regards to financial or time resources saved: for example, one could ask participants if they expected that CAVs would help driving become cheaper, for example due to lower insurance rates (Schoettle & Sivak, 2014a) or if they could help balance demand/supply, so that systems can suggest the best possible time and route to drive to receive a time/cost optimisation (Gruel & Stanford, 2016).

Finally, to cover broader societal impacts of CAVs in terms of usefulness, it might be important to ask participants whether they believe automated vehicles could increase accessibility to jobs, provide better job opportunities, leisure, and resources for both low and high-income groups, and increase disposable income along with travel (Childress, Nichols, Charlton, & Coe, 2015).

Perceived usefulness could also be studied from the perspective of willingness of users to adopt or to pay for useful services that have been specified. Nordhoff, de Winter, Madigan, et al., (2018) asked participants, after a shuttle experience, whether they would be willing to use the shuttle again to replace current options; in a similar study, participants agreed that it would be a potentially useful addition to the public transportation network for smaller routes that may not be served by large buses (Eden, Nanchen, Ramseyer, & Evéquoz, 2017). In terms of willingness to pay, availability of automated parking could for example be specifically selected as a useful feature and participants would be asked, how much they might pay extra for this (Payre et al., 2014). One could also ask participants if they would be more willing to pay for parking and multi-tasking benefits (Howard & Dai, 2014), for example for a self-parking valet technology (Bansal & Kockelman, 2017).

Based on the reviewed literature, items have also been constructed in WP3 for the representative survey, which include indicators to measure worse/better work productivity, shorter/longer travel times, less/more expensive travel cost, lower/higher status with acquaintances due to use, lower/higher status in society due to use and more beautiful/uglier environment.

2.8.2 Solution-specific indicators

While most mentioned items can be easily adapted to a variety of solutions, specific items can be developed for cases such as an owned vehicle of Level 3 automation, such as “I would rather use the automated driving system on the highway than driving by myself,” (Payre et al., 2014).

Additionally, some features that are available in owned cars are not available in shared cars and shuttled and vice versa, as well as helishuttles, so these should be listed in detail and asked for when asking for usefulness of specific solutions. As an example, items that have been used for autonomous shuttles are, “The best part of the self-driving bus is that it can be requested on demand.” and “I think that using the self-driving bus is more convenient than using regular buses for x reason.” (Wien, 2019).

Additionally, Distler et al., (2018) developed the following items (see Table 16) specific to autonomous shuttles that could be adapted further for different levels of automation.

Table 16: Items measuring perceived usefulness of autonomous vehicles (Distler et al., 2018)

Items
"On demand transport can help individualize travelers' needs."
"Autonomous shuttles can be a solution in case somebody is unable to drive, if you need to bring kids to school, for disabled persons, for the elderly…"
"It is good that one can take the shuttle anywhere and anytime."
"The autonomy of the shuttle was not flagrant compared to other means of public transportation."
"We would have been faster walking."
"The shuttle could help to go to areas which are currently not accessible by public transport, it would be a good complement to traditional public transport.
"This was very inefficient."
"If this would not have been an organized experience, we would not have waited for the shuttle. We would have walked to our destination."
"The autonomous shuttle needs to help me optimize my trips and make me win efficiency and time."

For Level 5 automation, usefulness extends to the ability to cover physical inability to drive, which might also be interesting to cover, such as done by (Payre et al., 2014), "I would delegate the driving to the automated driving system if:

- I was over the drink driving limit;
- I was tired;
- I took medication that affected my ability to drive."

Finally, some items can and should be adapted to emergency vehicles, though no studies exist as of yet that present specific indicators or items to measure perceived usefulness in implementation of automated technology in emergency vehicles.

Table 17: Perceived usefulness - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles	x	x	x

2.8.3 Data collection

The indicators for the measuring of perceived usefulness can be employed in a variety of data collection contexts. In particular for data collection in PAsCAL, the table below provides an overview over feasible inclusions.

All items and scenarios listed could potentially be included in a survey to measure general public responses for example; however, it would best to select the items that best match the purpose of the survey.

Usefulness indicators can also be used in observational trials for data collection, for example, by measuring how often or how much time participants spend in a CAV, or by providing surveys or interview opportunities after a scenario experience.

In the course of experimental field trials or VR/Home driving systems, participants could be asked to ride a CAV, with the intention to measure time spent inside the vehicle, or asking participants after their experience how much they would be willing to pay for individual useful features that were included in the field trials.

Table 18: Perceived usefulness - Overview over data collection possibilities

Data Collection	Representative Survey (WP3)	Observational trial (WP6)	Experimental field trial (WP6)	Lab trials (i.e. VR) (WP4)	Computational simulation (WP7)
Possible inclusion	x	x	x	x	

2.9 **Attitudes**

2.9.1 General concept indicators

Attitudes are psychological constructs characterizing a person’s values and complex mental states; they are usually obtained through experience (Allport, 1935). It can be said to be the reaction of people to places, things or events (objects of attitudes), which in turn affect the thinking and behavior of the individual.

As per definition one can measure attitudes towards an object such as a CAV or an autonomous technology by simply asking for the liking of the solution (for example on a Likert scale 1-7, bad to good), a person’s thoughts about the solution (Likert scale 1-7, worrisome - hopeful) and the spontaneous attitude (Likert scale 1-7, negative - positive), as developed by WP3 based on the Literature covered in previous sections. Items such as “Autonomous vehicles should play an important role in our mobility system” or “"How do you feel about sending an empty autonomous car to pick up your groceries?" have also been employed before (Haboucha et al., 2017).

2.9.2 Solution specific indicators

Any of these items can be adapted to target specific solutions listed in the table below.

Table 19: Attitudes - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles	x	x	x

2.9.3 Data collection

Measurement for Attitudes can be employed in a variety of data collection contexts. In particular for data collection in PAsCAL, Table 20 provides an overview over feasible inclusions.

All items listed can be included in a survey to measure general public responses for example. General attitudes can also be observed by rating the facial expression of participants in drives with CAVs or in-home system simulators and experimental field trials, or providing them with surveys assessing their attitudes afterwards. Additional proxies for attitudes could be time spent in a vehicle, frequency of drives a person is willing to undertake and willingness to let others use the vehicle.

Table 20: Attitudes - Overview over data collection possibilities

Data Collection	Representative Survey	Observational trial	Experimental field trial	Lab trials	Computational simulation
Possible inclusion	x	x	x	x	

2.10 Human Factors

In this section, we want to shortly summarize suggestions, ideas and recommendations regarding human factors from previous literature. We focus on (ergonomic) human-machine interactions in autonomous vehicles.

2.10.1 Research questions and challenges

Three fundamental research questions were identified by Debernard et al., (2016) to orientate the interface design. KPIs could be measured based on responses given to these questions.

1. In autonomous mode and in handover processing, which representation should the driver maintain or establish? According to the Situation Awareness model defined by Endsley, this question may be subdivided into three sub-questions:
    a. What should the driver perceive?
    b. What should he/she understand?
    c. Which projection of the external environment and the system should he/she perform?

2. How should we design the displays?
    a. What should be displayed?
    b. How should that information be displayed?
    c. When should it be displayed?
    d. With which prioritization?

3. What is the added-value of Augmented Reality in the displays? In other words, can driver maneuvers be impacted by Augmented Reality?

To answer these questions, other authors focused on problems and challenges that occur in human-machine interactions and solutions to overcome them (for example, Saffarian et al., 2012). In their paper, they write that despite technological issues that challenge the public use of autonomous vehicles, human factor issues of safety, usability and acceptance must also be considered. Challenges of interaction between human and automation include:

a. Overreliance – human does not question performance of automation, loss of vigilance;
b. Behavioral Adaptation – the perceived risk of drivers may be more tempted to engage in other activities;

c. Erratic Mental Workload – automation can increase mental workload in unexpected situations;
d. Skill Degradation – automation results in loss of manual control skills and degradation of the required cognitive skills;
e. Reduced Situation Awareness – high levels of automation can result in degraded event detection and response;
f. Inadequate Model of Automation Functioning - drivers could fail to reclaim control of the vehicle due to not understanding the ACC's functional limitations.

KPIs would here be evaluating by measuring users on these factors to see how CAVs affect them.

Interaction between human and machine takes place mainly for two main functions:

1. **Authority Transition**
   The timing and procedure of transferring responsibility from the human to automation system and vice versa. A proper system should avoid surprises and facilitate trust on automation. Humans should be aware of the limits of automation systems.
2. **Human-to-Vehicle Instruction and Vehicle-to-Human Feedback**
   Feedback should be provided in a timely and useful manner. Too early or inappropriate feedback may result in distraction, ignoring or shutting down the alarm system entirely. Also, whereas salient warnings are annoying, humans may miss non-salient warnings. Setting customization (displays and automation settings) can be a double-edged sword because of potential confusion by other users.

Solutions for Human-Machine Interaction may be:

1. **Shared control**
   Shared control is a framework, whereby human and automation cooperate to achieve the required control action together. This keeps drivers involved in the control loop, allows them to understand the system's capability and supports the acquisition of situation awareness with a minimum of cognitive effort.
2. **Adaptive Automation**
   Adaptive interfaces can reduce the driver's mental workload by presenting information according to situation requirements (e.g. driving conditions, driver's population). Adaptive automation can also monitor and alert drivers to their impairments (e.g. drowsiness).
3. **Use of an Information Portal**

   Information portals should provide relevant information at the suitable moment, communicate required actions and provide feedback.

4. **New Training Methods**
   Changings in driving licensing and driver training may be needed, because psychomotor skills become less and computer skills and mode-conflict resolution more relevant. A consistent, accurate and tireless automated trainer and sensor systems can capture every event and reveal errors that might be unnoticed by a human trainer.

The authors propose using the Cooperative Adaptive Cruise Control (CACC) system, which enables a platoon of two or more vehicles driving with automated longitudinal control at a set distance parameter through shared kinematic information. CACC cars can outperform humans e.g. in traffic flow, eco-driving and safety in conditions of reduced visibility (night, fog...) and driving long periods.

Design requirements for CACC are as follows (assuming all vehicles are equipped with equivalent CACC systems). KPIs could measure acceptance of these designs for example via surveys or via VR experiences.

1. **System Initialization**
   The system should make drivers aware whether the CACC is enabled or not. Initialization should provide clear information of what the headway and speed settings imply in terms of stopping distance and hazard and retrieve and change these settings. The initialization setting should not post too much extra workload on drivers.
2. **Platooning (stationary motion)**
   The tailgating behavior of CACC should gain acceptance of drivers. They should not experience automation surprises. The system should communicate constraints that driving in platoons pose and drivers should have an option to come out of the platoon in a safe and smooth manner.
3. **Joining and Splitting (transition maneuvers)**
   Joining and Splitting should be performed with as few steps as possible to avoid confusion.

2.10.2 Considerations of safety and risk in human factors research

Elbanhawi, Simic, & Jazar, (2015) introduce the concept of “the loss of driver controllability”, the paradigm shift from the role of humans as drivers to the role of passengers in autonomous cars. Technological advance has been used to find optimal solutions for path planning (the generation of a continuous set of actions whilst considering both, vehicles and environmental limitations), but human related factors, such as passenger comfort, are ignored in planning.

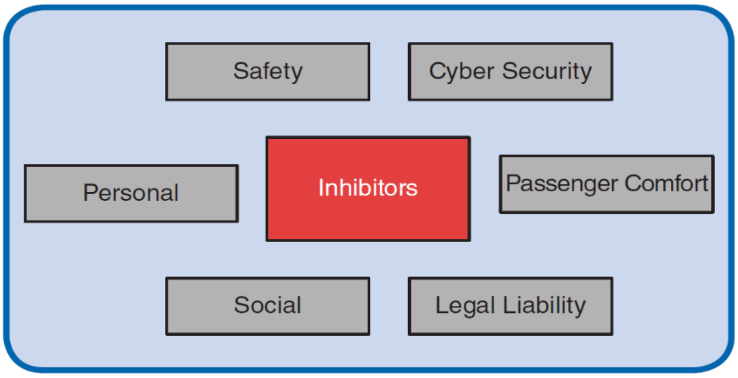


FIG 2 Factors that arise with autonomous vehicle use.

Figure 16: Factors that arise with autonomous vehicle use.

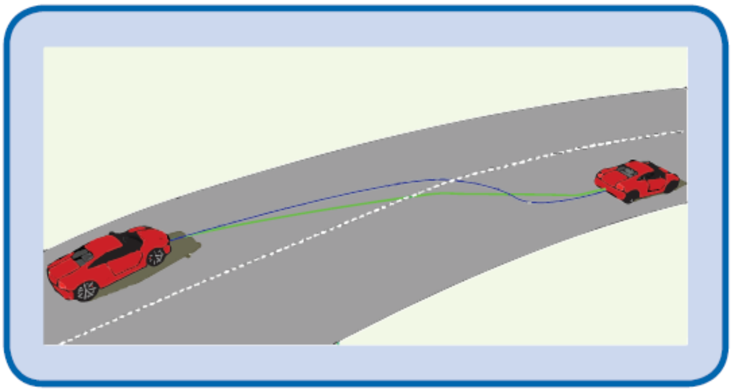


FIG 1 The concept of passenger aware paths (blue) as opposed to optimal paths (green) in a lane-changing maneuver.

Figure 17: Concepts of passenger paths vs optional paths in lane-changing.

Research shows, that once drivers were relieved from the control role, several concerns were raised with respect to the operation of autonomous vehicle.

KPIs should measure the developments on the following factors in order to understand better the relationship between humans and CAVs.

Liability: In cases of an accident, which party assumes responsibility?

Social/Economic: Will an autonomous car sharing system be needed or will people still rely on individual car ownership?

Personal: Is the public ready to adopt autonomous vehicles?

Legislative: Will driving licenses still be needed?

2.10.3 Considerations of comfort and ergonomics

Traditionally, researchers have investigated ergonomic (see Figure below, blue), but the loss of controllability in autonomous cars would lead to a shift towards other factory, such as vehicle control, motion sickness and safe distance keeping (Figure 18: Factors influencing ride comfort. Figure below, red).

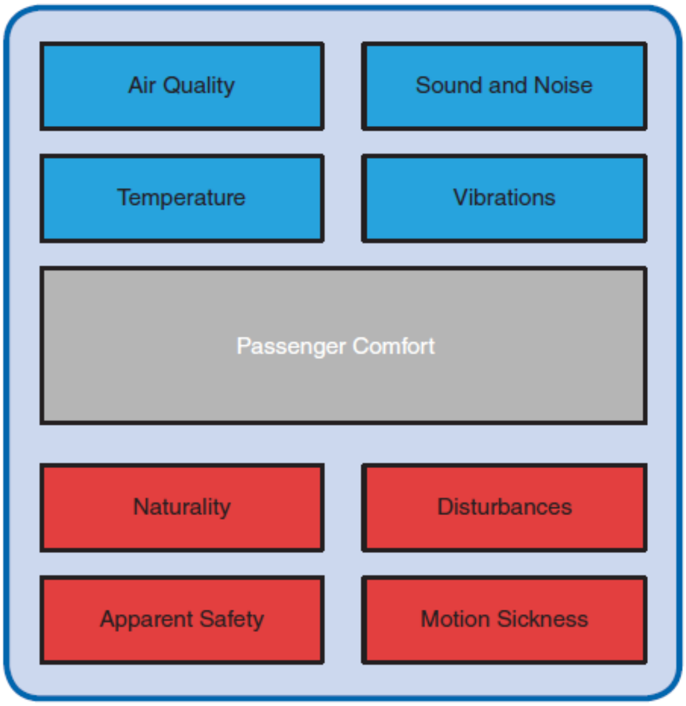


FIG 5 Factors influencing ride comfort in traditional (blue) and autonomous (red) cars.

Figure 18: Factors influencing ride comfort.

Normally, noise, vibrations and harshness are prioritized in vehicle design. Drivers experience two types of disturbances: road and load disturbances. The latter low frequency/high magnitude disturbance) originates from driver's control of braking, acceleration and turning. All these could be asked via survey or interviews of participants after experiencing a CAV to measure KPIs for human machine interaction on the dimension of comfort.

High frequency/low magnitude disturbances can result from the road vehicle interaction. Vehicle suspension designs have been proposed to improve passenger comfort by accounting for vertical road vibrations and pitch oscillations. Seat structures could also have an influence on ride comfort measures. Also, noise and acoustic metrics (sound level, frequency, tonality) are contributing factors to passenger comfort.

The development of Driver-Vehicle-Interface (DVI) may further improve passenger comfort and limit the operator distraction, e.g. by reducing driver diversion, giving feedback of leading traffic distance and improving driver performance and comfort though in-vehicle-entertainment (e.g. music). Research on Augmented Reality applications could provide possible methods for the future design of DVI, and the here mentioned factors should be measured according to this.

In Figure 18 passenger-aware planning factors were mentioned. These criteria have been investigated separately, but a holistic approach for passenger awareness is still lacking. The need for addressing motion sickness, natural path synthesis and apparent safety could be addressed as well to gather KPIs in this area.

3 Indicators of acceptance by road co-users

Research dealing with autonomous solutions has so far focused on the public as potential passengers of autonomous cars, largely overlooking road co-users as potential research subjects. Indeed, most of the time autonomous vehicles have been studied only independent of their interaction with other modes of transport, limited in terms of their movements and interactions. As CAVs will be on the roads, in public spaces, and in constant complex interaction with others, inclusion of pedestrians, cyclists, and perceptions of drivers of other existing vehicles are of paramount importance to increase acceptance, and in particular the safety, of autonomous vehicles.

In this document, we want to closer examine two major areas of road co-user acceptance – perceived risk and willingness to accept in combination with attitudes.

3.1 Perceived Risk

Safety and security concerns impact pedestrian and cyclists' perceived risk from CAVs. The detection of other vehicles and road users has been a topic (Litman, 2019; Häne et al., 2015), as well as the design of the vehicles and their external interfaces (Deb et al., 2017); here, interactions of road co-users and CAVs were investigated, and it was found that automation cannot substitute for a human driver, and that the perspective of pedestrian, cyclists, wheelchair users towards the technology needs to be further researched.

A number of studies that deal with the topic of CAVs more broadly have mentioned pedestrian and bicyclist safety as an issue, though most of them don't specifically generate indicators for measuring these issues. (Elliott, Keen, & Miao, 2019; Hulse, Xie, & Galea, 2018; Rothenbücher, Li, Sirkin, Mok, & Ju, 2016).

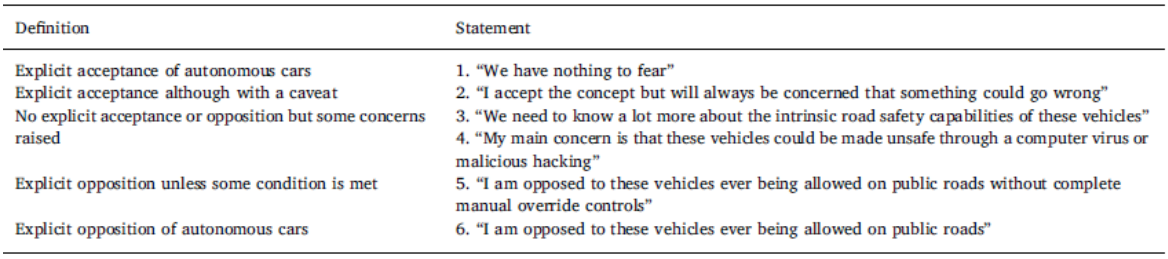
In one field study, researchers investigated risk perception directly: the authors interviewed pedestrians and bicyclists on their subjective risk perception after an encounter with a "false" autonomous vehicle on a crossroad: the authors found that there is a paradoxical combination of distrust due to lack of human driver, and trust due to the conceptual understanding that an algorithm can make more accurate decisions than humans (Rothenbücher et al., 2016).

Road user interaction can also be measured via game theoretic frameworks in simulations studying the cost benefit structure of crossing the road for pedestrians, for example, at the risk of traffic citation or accident (Millard-Ball, 2018).

In terms of perceived risk from the perspective of bicyclists, (Dill and McNeil, 2013) found that most cyclists were interested but concerned about the technology, and (Wood et al., 2009) found that environmental conditions and the issue of overtaking safety were the most commonly named concern with regards to driving safety.

Finally, a list of potential indicators that could be used to measure perceived risk can be taken from a study by (Hulse et al., 2018), see Table 21.

Table 21: Items of road co-user acceptance specifically referencing perceived risk (Hulse et al., 2018)



Definition	Statement
Explicit acceptance of autonomous cars	1. "We have nothing to fear"
Explicit acceptance although with a caveat	2. "I accept the concept but will always be concerned that something could go wrong"
No explicit acceptance or opposition but some concerns raised	3. "We need to know a lot more about the intrinsic road safety capabilities of these vehicles" 4. "My main concern is that these vehicles could be made unsafe through a computer virus or malicious hacking"
Explicit opposition unless some condition is met	5. "I am opposed to these vehicles ever being allowed on public roads without complete manual override controls"
Explicit opposition of autonomous cars	6. "I am opposed to these vehicles ever being allowed on public roads"

In the same study, participants were asked to rate the level of risk they associated with various modes of transport, from the point of view of different populations. The populations were the following:

- the driver/rider of a human-operated car, motorcycle and bicycle;
- a passenger of a train and car, both human-operated and autonomous;
- a pedestrian in an area with cars, human-operated and autonomous.

In this study, risk was defined as "the potential for an accident to occur, resulting in unwanted negative consequences to one's own life or health" and, with the exception of trains, participants were provided with the context of travelling in "heavy traffic".

Perceived risk ratings were made using a seven-point scale (where 1= “Extremely Low”, 2 = “Moderately Low”, 3 = “Somewhat Low”, 4 = “Not Sure”, 5 = “Somewhat High”, 6 = “Moderately High”, and 7 = “Extremely High”). (Hulse et al., 2018)

However, perceived risk is not only a factor of the target, but also of the behavior of road co-user themselves. In previous studies on these behaviors, for example in (Hulse et al., 2018), instruments were used listing behaviors using a seven-point scale. Items such as “Crossing the road when the ‘don’t walk’ sign is indicated” self-generated, and items such as “Walking home alone at night in an unlit area of town” and “Riding a bicycle without wearing a helmet” taken from the Health/Safety subscale of the DOSPERT Risk-Taking Scale were included (Blais and Weber, 2006).

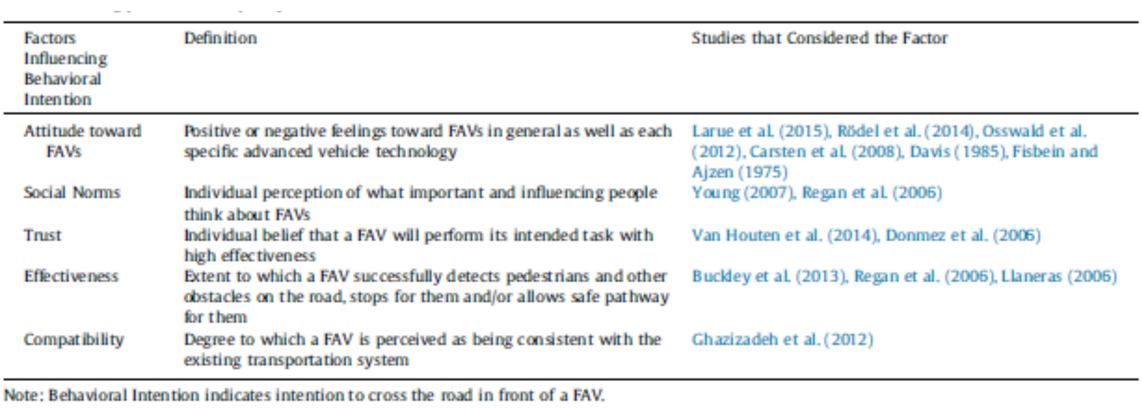
Across the literature, it can be summarised that the greater focus is on improving vehicle-pedestrian interaction in terms of interaction design (Millard-Ball, 2018; Rasouli & Tsotsos, 2019).

In the context of WP3, based on the literature surveyed, indicators for PAsCAL were developed also for the perspective of the road co-user’s perception of safety, including perceived frequency of accidents (going up or down), and items on whether road co-users feel that CAVs would make travelling in general more or less dangerous.

3.2 Attitudes and willingness to accept

As part of their study, (Deb et al., 2017) developed a list of factors influencing road co-user receptivity towards CAVs and their definitions, which can be seen in Table 22. More specific items will not be discussed here, but can be further investigated in the column of the table listing studies that have investigated different factors.

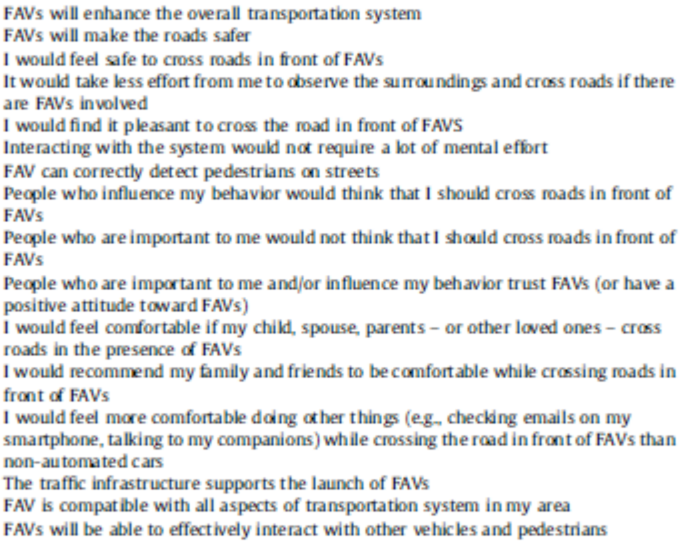
Table 22: Factors affecting pedestrian receptivity towards fully autonomous vehicles (Deb et al., 2017)



Factors Influencing Behavioral Intention	Definition	Studies that Considered the Factor
Attitude toward FAVs	Positive or negative feelings toward FAVs in general as well as each specific advanced vehicle technology	Larue et al. (2015), Rödel et al. (2014), Osswald et al. (2012), Carsten et al. (2008), Davis (1985), Fisbein and Ajzen (1975)
Social Norms	Individual perception of what important and influencing people think about FAVs	Young (2007), Regan et al. (2006)
Trust	Individual belief that a FAV will perform its intended task with high effectiveness	Van Houten et al. (2014), Donmez et al. (2006)
Effectiveness	Extent to which a FAV successfully detects pedestrians and other obstacles on the road, stops for them and/or allows safe pathway for them	Buckley et al. (2013), Regan et al. (2006), Llaneras (2006)
Compatibility	Degree to which a FAV is perceived as being consistent with the existing transportation system	Ghazizadeh et al. (2012)

Note: Behavioral Intention indicates intention to cross the road in front of a FAV.

Additionally, a list of items was developed by (Deb et al., 2017) targeting more general attitudes about CAVs, which were also considered in the context of road co-users and their perceptions. These items can be seen in Figure 19.



FAVs will enhance the overall transportation system
FAVs will make the roads safer
I would feel safe to cross roads in front of FAVs
It would take less effort from me to observe the surroundings and cross roads if there are FAVs involved
I would find it pleasant to cross the road in front of FAVS
Interacting with the system would not require a lot of mental effort
FAV can correctly detect pedestrians on streets
People who influence my behavior would think that I should cross roads in front of FAVs
People who are important to me would not think that I should cross roads in front of FAVs
People who are important to me and/or influence my behavior trust FAVs (or have a positive attitude toward FAVs)
I would feel comfortable if my child, spouse, parents – or other loved ones – cross roads in the presence of FAVs
I would recommend my family and friends to be comfortable while crossing roads in front of FAVs
I would feel more comfortable doing other things (e.g., checking emails on my smartphone, talking to my companions) while crossing the road in front of FAVs than non-automated cars
The traffic infrastructure supports the launch of FAVs
FAV is compatible with all aspects of transportation system in my area
FAVs will be able to effectively interact with other vehicles and pedestrians

Figure 19: Items covering perception and attitude towards fully autonomous vehicles (Deb et al., 2017)

Similar to the study mentioned above, WP3 also measures general attitude items, which can be employed for users of mobility for all perspectives onto CAVs, drivers and road co-users. These items include concepts such as liking of the solution (1-7, bad to good), thoughts about solution (1-7 worrisome - hopeful), the spontaneous attitude (1-7 negative - positive), and questions about whether the road co-users would like/would not like to use the solution in general if it was available, whether they thought politicians should prevent the introduction of autonomous solutions; whether they themselves would try to avoid the solution as much as possible, and whether they would try to actively hinder the solution.

3.3 Data collection

For the items and scenarios listed in 3.1 and 3.2, a variety of data collection possibilities exist. Within PAsCAL, many will be included in the WP3 survey where participants will be able, on one hand to choose their own perspective (as a driver or a as a road co-user), on the other hand it will be experimentally assigned to one perspective.

Reactions of road co-users to CAVs can also be studied in observational trials, for example by letting pedestrians and cyclists interact with an autonomous shuttle near bus stops. This could also be done in the course of an experimental field trial or lab trial with VR or home simulation systems where participants can be assigned different perspectives (car user vs pedestrian, etc.).

Finally, game theoretic approaches such as the one described in 3.1 can be taken to simulate possible interactions between groups of road co-users and CAVs.

Table 23: Perceived usefulness - Overview over data collection possibilities

Data Collection	Representative Survey (WP3)	Observational trial (WP6)	Experimental field trial (WP6)	Lab trials (i.e. VR) (WP4)	Computational simulation (WP7)
Possible inclusion	x	x	x	x	x

4 Indicators of acceptance by vulnerable user groups

Due to the level and characteristics of their vulnerability, the identified user groups (i.e. elderly, impaired, gender related, children, persons living in rural areas, etc.) have different needs in terms of the physical design of the CAV and related mobility offer. In general, they need more assistance in reaching the vehicle, boarding and travel. Research shows that elderly make on average shorter daily trips of which most are done just after morning peak hours (Kaniz et al. 2018). They have the need for a different mobility offer than the average commuter.

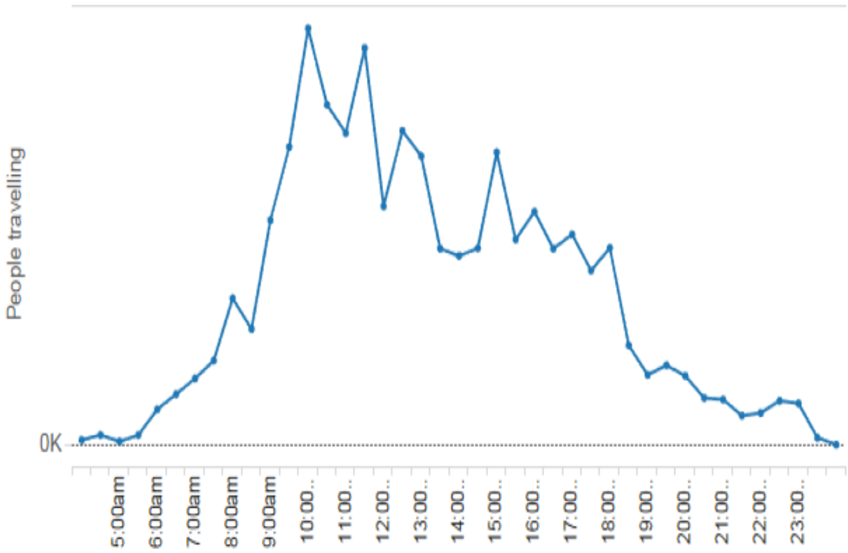


Figure 20: Number of elderly people traveling (VISTA 2012 in Kaniz et Al. 2018)

The different KPI's defined for vulnerable user groups aim three distinct levels of usefulness. Firstly, a set of indicators can be defined related to the specific physical encounter and usage of the CAV. Within PAsCAL this will specifically be measured through levels of adequacy of the features and services provided. Secondly, the effects can be measured at the level of the changed transport offer for vulnerable groups as the result of the introduction of CAV and services. In the PAsCAL project this will be measured through changed levels of availability, accessibility and affordability. Finally, the effect of CAV on vulnerable groups can be measured at the societal level. Within the PAsCAL project this will be measured specifically in terms of social inclusion, human dignity and ethics. In the following paragraphs the different KPI's are discussed in more detail.

4.1 Availability of the solution

4.1.1 General concept indicators

When speaking in literature about "availability" the terms "access," "accessibility," and "proximity" have been used in various studies with similar meaning (Bok et al. 2015). Availability in transport planning related literature is sometimes referred to as accessibility. In PAsCAL "Accessibility" is used in terms of "accessibility to basic societal services" by vulnerable groups.

Availability refers to the level of actual availability of the CAV service, as to say, will there be a changed transportation offer as the result of CAV. Measurement of availability will much depend on the specific service format offered (individual vehicle, shared vehicle, public transport) and/or CAV feature tested.

In the case of an individual or shared vehicle, the CAV feature allows the vulnerable group user to have an increased offer. This can be defined in terms of how much the vehicle becomes actually available for usage or how much more services will become available for usage. This can for example be measured through a survey in the format of a conjoint or discrete choice analyses (Breidert et al. 2015) in case of multiple scenarios while using the following indicator:

- Level of vehicle availability (absolute numbers, % change);
- Number of additional vehicles available.

When assessing availability in relation to a shared or public transport services, the availability can also be measured as an increased availability of the transport service offers:

- Level of frequency (number of trips per hour);
- Change distance of the point of departure and/ or arrival (measured in meters).

In terms of the frequency, the peak service level as well as the average service level per day are of importance. As mentioned earlier it is not uncommon for members of vulnerable groups to travel outside of peak hours. Operational frequencies in that respect can been measured as trips per hour by taking the average of schedules during specific hours of the day.

4.1.2 Solution-specific indicators

Any of these items can be adapted to target specific solutions listed in the table below. Yet specifically the frequency and distance related KPI's seem to be more usable in the frame of shared and public transport related surveys and modelling.

Table 24: Availability of the solution – Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles	x	x	x

4.1.3 Data collection

The indicators can be measured through a representative survey in which the respondents are asked to state their opinions on levels of expected availability. Through experimental field trials the availability of a specific form of transport in the frame of a specific service format offered (shared vehicles, public transport, emergency vehicles) could be tested. Likewise this could be tested in a computational simulation which could calculate if the services becomes more available as the result of a tested CAV features service taking into account more contextual aspects. So in particular for data collection in PAsCAL in the frame of the “emergency vehicles” pilot in Madrid and the “shared connected vehicles” in Germany this might be feasible. The table belowTable 4 provides an overview of the feasible inclusions in the PAsCAL project.

Table 25: Availability of the solution - Overview over data collection possibilities

Data Collection	**Representative Survey**	**Observational trial**	**Experimental field trial**	**VR / Home system**	**Computational simulation**
Possible inclusion	x		x		x

4.2 Adequacy of the solution

4.2.1 General concept indicators

Adequacy of the CAV features and services for the vulnerable groups relate to the extent to which it caters for the specific requirements (e.g. wayfinding, availability of specific safety indication, access to complementary assistance whether it be mechanical, physical and informational) in reaching, boarding and traveling with the vehicle making and/or use of the wider CAV services. Specifically, to be mentioned in the case of travellers with mobility constraints, this relates to the possibility to connect (or not) to the CAV vehicle and services specific devices already being used by them (wheelchairs, speech to braille translators, etc.).

Depending if the specific feature services are at the design stage or operationally implemented, there are several methods that can be used to measure the level of adequacy. In the case of a technological acceptance model type of evaluation, specific factors are of more importance when involving vulnerable groups. These are measures that specifically relate to the measurement of the adequacy of facilitating conditions, self-efficacy yet also potential levels of anxiety (adapted from Osswald, 2012).

Table 26: Factors and possible measurements of adequacy of autonomous solutions

Factor	**Possible measurement**
Facilitating conditions	While using the system I can maintain a safely driving behaviour. I have the knowledge necessary to use the system. The system is compatible with other systems I use. There would be somebody I can ask for assistance with system difficulties.
Self-efficacy	I could complete a task or activity using the system… … if there was no one around to tell me what to do. … if I could call someone for help if I got stuck. … if I had a lot of time. … if I had just the built-in help facility for assistance.
Anxiety	I have concerns about using the system. I think I could have an accident because of using the system. The system is somewhat frightening to me. I fear that I do not reach my destination because of the system.

4.2.2 Solution-specific indicators

Depending on the setup of the trials, experiment and pilot any of these items can be adapted to target specific solutions listed in the table below. Of particular interest might be adapting them to the adequacy of emergency vehicles to serve the needs of vulnerable user groups such as people with reduced mobility.

Table 27: Adequacy of the solution - Overview over solutions

CAV Solutions	**Level 3 (conditional automation)**	**Level 4 (high automation)**	**Level 5 (full automation)**
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles	x	x	x

4.2.3 Data collection

The indicators for measuring adequacy can be specifically obtained in the frame of observational trials in laboratories and experimental field trials. They can also be employed in a variety of data collection contexts, no matter if it involves a larger group of vulnerable users in the frame of autonomous bus testing, participants to a driver training in a safe driving training centre, or a small group in the frame of a driving simulator. The table below provides an overview over feasible inclusions. As the KPI is specifically measured in the frame of human-machine encounters it is thought to be less relevant in the frame of a representative survey as well as computational simulations.

Table 28: Adequacy - Overview over data collection possibilities

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion		x	x	x	

4.3 Accessibility

4.3.1 General concept indicators

Whereas in terms of availability the focus is on the offer and the actual presence of a vehicle, with accessibility in the case of the PAsCAL project the focus is on the possibility to reach a certain destination. Accessibility is defined as to which extend CAV and services provide suitable transport to key activities such as education, employment, health and leisure (e.g. visiting friends, shopping). Some studies show that the travel needs for certain activities increase depending on the characteristic of the vulnerability. The travel need of the older population may be specifically increased for non-home activities such as social services and health care (Kaniz et al. 2018).

The related KPI's are therefore more relevant in relation to the specific shared or public services offered as a result of CAV. Services that lead to an increase access to specific activities and destinations. Means to measure such KPI's are often defined in terms overall network performance such as:

- % of vulnerable group travellers have direct journeys to certain destinations;
- Number of destinations that can be reached within a defined distance and set time limit by a specific vulnerable group;

- Level of service provision provided suitable for a specific vulnerable group.

4.3.2 Solution-specific indicators

Any of these items can be adapted to target specific solutions listed in the table below. As said, these type of indicators are expected to be of relevance in the frame of the shared vehicle and autonomous bus related pilots, yet might also be able to be calculated/ modelled in the frame of the other tested means (Heli shuttle and emergency vehicles) in the frame of the PAsCAL project. They are expected to be of less relevance in the frame of individual car usage.

Table 29: Accessibility - Overview over solution

CAV Solutions	**Level 3 (conditional automation)**	**Level 4 (high automation)**	**Level 5 (full automation)**
Owned car			
Rented car			
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles	x	x	x

4.3.3 Data collection

In the frame of the Pascal project it looks like that the KPI of accessibility is specifically of use in the frame of a representative survey with stated opinions on the changed level of accessibility as the result of a certain CAV service provided. Also, in the frame of the computational simulation of levels of service provision this indicator might be able to be calculated.

Table 30: Accessibility - Overview over data collection possibilities

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x				x

4.4 Affordability

4.4.1 General concept indicators

Transport affordability in general relates to the financial costs of households for transportation and specifically the ones related to education, employment, healthcare and basic social activities. They are on average about 20% of the income. Nevertheless, it is shown that in the case of vulnerable groups they can reach up to 45% (Litman, 2017). Due to their place of housing, impairment, and needed assistance in their mobility, vulnerable groups are often condemned to ownership or being a passenger of a private car to fulfil part of the basic household needs. So, when assessing the affordability of tested CAV features and concepts, the changed percentage of household income costs in comparison to the preceding situations could be assessed. Affordability could also be expressed in terms of absolute costs, wherewith one should not forget upfront costs such as insurance (Cavoli et al. 2017). Identified KPI's are:

- % of household income change of a specific vulnerable group;
- Absolute cost change for a specific vulnerable group.

4.4.2 Solution-specific indicators

Any of these items can be adapted to target specific solutions listed in the table below as long the related costs (absolute cost or cost difference) or vehicles without the specific CAV feature or services can be calculated. Emergency vehicles are upfront excluded as these are in general not directly at the costs of the user.

Table 31: Affordability - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	X	X	X
Rented car	X	X	X
Shared car/shuttle	X	X	X
Public transport	X	X	X
Helishuttle	X	X	X
Emergency vehicles			

4.4.3 Data collection

The affordability indicators can be employed in a variety of data collection setups. In order to obtain an indication of the level of affordability in the trials and pilots, there is the need for some modeling on the basis of an initial estimation of the basic cost items. In particular in the frame of the data collection in PAsCAL it is expected that specifically a representative survey format, as well as the computational simulation might be used to obtain this indicator. Depending on the availability of data this might also be the case to a lesser extend in the frame of the experimental trials, specifically the one related to the "shared vehicles".

Table 32: Affordability - Overview over data collection possibilities

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x		x		x

4.5 Social inclusion

4.5.1 General concept indicators

Beyond a specific level of accessibility to certain services, social inclusion within the PAsCAL project relates to the level of which vulnerable group members can take part in society. For example, several studies show that older people make fewer trips because some of them find travelling with public transport difficult. Mobility related difficulties increase with age. Only 4% of younger people having such difficulties yet it increases to 17% for those aged 60–69 and to 39% for those aged 70 and over (Kaniz et al. 2018; Shresta et al. 2017). Bissel et al. (2018) showed also that CAV developments might lead to an intensified social segregation between the vulnerable groups and the so-called ‘kinetic elite’ (Elliott and Urry, 2010). The latter already experiencing a high level of mobility offer might further benefit as the result of CAV developments. On the other hand, vulnerable groups might risk further exclusion.

A specific KPI in relation to the PAsCAL project in that respect might be the measured difference in which the different vulnerable groups have access, availability and affordability to CAV services and societal activities yet also higher levels of flexibility and comfort in comparison with the non-vulnerable groups. This impact on social inclusion might be measured through percentages of difference between user categories in the frame of a survey or a modelling.

- Level of vehicles available (absolute numbers, % change) in comparison with non-vulnerable groups;
- Level of available frequency (number of trips per hour) in comparison with non-vulnerable groups;

- % change distance of the point of departure and/ or arrival (measured in meters) in comparison with non-vulnerable groups;
- Difference in % change in direct journeys in comparison with non-vulnerable groups;
- Number of destinations that can be reached within defined distance and time limits by a specific vulnerable group in comparison with non-vulnerable groups;
- Difference of % of vulnerable groups household income change in comparison with non-vulnerable groups;
- Difference in absolute cost change as the result of introduced CAV feature in comparison with non-vulnerable groups.

4.5.2 Solution-specific indicators

Any of these items can be adapted to target specific solutions listed in the table below yet will much depend on the specific set up of the trials and pilots.

Table 33: Social inclusion - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles			

4.5.3 Data collection

The indicators for measuring changed levels of social inclusion can be employed in representative surveys and computational simulation. All indicators are thought to be of use in a survey that measures general public responses. If the basic data of accessibility, availability, and affordability are available through computational simulation it might also be possible to calculate at a more abstract level a changed level of social inclusion.

Table 34: Social Inclusion - Overview over data collection possibilities

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x				x

4.6 Human dignity and ethics

4.6.1 General concept indicators

Changing from human driven cars to automated driving will raise various ethical issues and links as well to the topic of human dignity. This relates to the morally problematic and sometimes rule breaking aspects of how many people presently drive and the development of new services and programming in which key ethical values need to be embedded and correctly matched with the freedom of choice, privacy and value of a human life. Specific measurement in terms of KPIs relate to the level of equal treatment in terms of safety and value of life in the logarithms, respect of privacy, and offered freedom of choice in the CAV services. Specific KPI's in this regard are:

- Level of equal treatment in terms of safety;
- Level of equal treatment in logarithms and developments as a result of estimated value of life;

- Level of privacy (ranging from public to private with intermediate stages);
- Level of freedom of choice as a result of the CAV services.

These are all rather high-level indicators that most likely can only be calculated through statistics or obtained in the frame of surveys.

4.6.2 Solution-specific indicators

Any of these items can be adapted to target specific solutions listed in the table below.

Table 35: Human dignity and ethics - Overview over solutions

CAV Solutions	**Level 3 (conditional automation)**	**Level 4 (high automation)**	**Level 5 (full automation)**
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles	x	x	x

4.6.3 Data collection

It is expected that in the frame of the PAsCAL project this indicator can only be obtained through a representative survey or expert interviews.

Table 36: Human dignity and ethics - Overview over data collection possibilities

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x				

5 Indicators of acceptance by other stakeholders

5.1 Local authorities: willingness to pay/invest in CAV technology

5.1.1 General concept indicators

Investment by municipalities in the future means of mobility solutions is an important strategic way for the deployment and acceptance of these solutions. A European report from the European Investment Bank (European Investment Bank, 2017) states that 42% of municipalities in the EU report an increase in investment activities in their jurisdictions over the last five years, and a rise in their own investment activities. Nevertheless, the consideration of self-driving and connected vehicles is not yet among the main concerns of municipalities, since 43% of municipalities expect their investment to focus on repair and maintenance in the next 5 years. Modernization and capacity expansion play a lesser role.

In terms of policy priorities, municipalities will focus their investment on making their infrastructure more socially inclusive. Investments related to public transport have increased by 33% in 5 years, but without anticipating future mobility solutions. These investments are not a priority, as the municipalities report an increase in infrastructure investment is highest for the ‘education’, ‘environment’ and ‘ICT’ sectors.

In another report (Driving the motor industry, 2019), it is considered that the deployment of autonomous and connected vehicles in UK will depend heavily on public investments in the field of telecommunications, particularly in the availability of communications infrastructure (4G mobile connectivity), especially on road networks. In this report, it is estimated that one in every five miles travelled by consumers in the UK could be automated by 2030. Moreover, in terms of economic impact for the municipalities or the countries, the report forecasts a total of £62 billion (€72 billion) in annual economic benefits for the UK from CAV deployment by 2030, with the impact on consumers worth some £46 billion (€54 billion) delivering the bulk of the prize. This is due to enhanced consumer productivity enabled by better in-car connectivity, improved travel efficiency and reduced mobility related expenses. For instance, current estimates based on our CAV roadmap indicate that CAV deployment can save every driving commuter nearly 42 hours in travel time, annually. Moreover, commuters stand to benefit from a 20% increase in average speeds per journey due to reduced congestion and smoother traffic flows. This forecast is calculated on the assumption that the UK government would need to incur a net expenditure of around £10 billion on infrastructure development which will be needed to sustain this growth scenario. This spend will need to focus primarily on providing the requisite digital infrastructure to support new modes of transport for consumers. This investment, especially in establishing the required infrastructure, will need to be made upfront to deliver the positive economic impacts indicated in the report.

Moreover, the contribution of autonomous and connected vehicles to the urban landscape might be a real added value for citizens, yet on the other hand make disappear certain jobs.. Fraedrich, Heinrichs, Bahamonde-Birke and Cyganski (2019) underline that the visions of integrating autonomous vehicles into the urban transport system refer to the development of the vehicle technology, the effects on traffic flow and potential benefits with respect to safety, congestion or emissions. Effects on parking as a result that autonomous vehicles (AV) can park themselves or remain in the transportation network while awaiting their next passenger showed significant impact on inner city street space usage.

In general, citizens health could be considered as impacted by connected and autonomous vehicles. For example, Milakis, Van Arem and Van Wee (2017) report a lot of studies which underline how CAV could significantly decrease travel time or traffic jam. Thus, the International Transport Forum reported a reduction of up to 37.9% compared to the current travel time of private cars in Lisbon (Portugal) based on a simulation study. Similarly, the authors show that automated driving might be able to reduce congestion by 50%, while this reduction could go even higher with the help of vehicle-to-vehicle and vehicle-to-infrastructure communication. On the other hand decrease the average passenger/car ratio under 1 and increase the car density with empty cars moving around to pick up their passengers

To finish, autonomous vehicles will develop the concept of carsharing (Lenz & Fraedrich, 2016). According to the authors, with the introduction of autonomous vehicles, it seems possible to appreciably extend and diversify existing mobility concepts, as carsharing. Accessing and egressing a vehicle is changing, in that the user no longer goes to the vehicle, but the vehicle comes to the user. Vehicles themselves are becoming usable for a wider section of the population, e.g. those with impaired mobility. New forms of public transport are possible, also in the sense of further blurring the boundaries between private and public transport.

5.1.2 Solution-specific indicators

Regarding the willingness to invest in CAV technology for municipalities, the specific solutions mainly concern a high level of automation (levels 4 and 5).

As noted earlier, connected and autonomous vehicles can be a source of revenue for municipalities, although other studies have suggested that these vehicles could result in cities losing money. For example, in addition to the studies cited above, Mike Maciag (https://www.governing.com/topics/finance/gov-cities-traffic-parking-revenue-driverless-cars.html) indicates that driverless vehicles would also cut into parking tickets and traffic citations, two significant revenue streams for many cities. It is estimated that New York city generated $1.2 billion in 2016.

Consequently, three main KPIs were identified and will influence municipal investment decisions:

- Estimated Value of the adoption of CAV (in €).
- Estimated investment of the municipality for the adoption of CAV for public purposes like public transport (in €).
- Estimated investment of the municipality for the adoption of CAV for citizens (in €).

Furthermore, the investment and in CAV vehicle will also have an impact on the local authorities' image. The adoption of the services proposed by municipalities and offered to citizens depends first and foremost on the perceived quality of these services. In this respect, the three specifics KPIs are based on subjective measures.

- Estimated added value in terms of reputation for the municipality (0-4 scale)
- Estimated added value of the public services offer (0-4 scale)
- Estimated added citizen well-being (0-4 scale)

Table 37: Local authorities: willingness to pay/invest in CAV technology-Overview over solutions

CAV Solutions	**Level 3 (conditional automation)**	**Level 4 (high automation)**	**Level 5 (full automation)**
Owned car		x	x
Rented car		x	x
Shared car/shuttle		x	x
Public transport		x	x
Helishuttle		x	x
Emergency vehicles		x	x

5.1.3 Data collection

Given the nature of the data to be collected and the target of the first three indicators (the municipalities), we believe that these data could only be collected through representative surveys and field experiments, which would directly or indirectly involve the municipalities, especially their public transport management teams.

For the last indicators, this type of subjective data can be collected through the dissemination of questionnaires, such as the one disseminated in the framework of WP3, as well as during field experiments, directly from the participants in the pilots in WP6 (especially the pilots “Shared connected transport”, “SMEV - Smart Emergency Response”, “Experience of vulnerable travelers with connected transport environment” and “High-capacity autonomous bus operations”).

Table 38: Local authorities: willingness to pay/invest in CAV technology - Overview over data collection possibilities

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x		x		

5.2 Local authorities: willingness to pay/invest in new or adapted infrastructures

5.2.1 General concept indicators

Changing existing infrastructure is also at the heart of the changes brought about by autonomous and connected vehicles within municipalities. According to Fraedrich, Heinrichs, Bahamonde-Birke, and Cyganski (2019), fully automated driving will entail a completely new transport system, which will not only bring new possibilities and new types of transport provision, but is also likely to strongly interact with the built environment and, therefore, touch the domain of city planning. A few existing studies investigate the link between AV and urban form, land use, urban infrastructures and the implications for city planning. These studies indicate several areas where AV are likely to influence the built environment. Among the key themes are i) changes in the required road space (rights-of-way and travel lanes) and infrastructures (signage, etc.), ii) effects on the location, form, and amount of parking, iii) interactions with the mobility of cyclists and pedestrians, iv) opportunities for redevelopment of land-use, and v) land-use changes and residential relocation.

5.2.2 Solution-specific indicators

If CAV would probably need to change infrastructure, it is difficult to predict and anticipate exactly the new kinds of infrastructure that would be needed (Guerra, 2015). Milakis, Van Arem and Van Wee (2017) estimate that increased road capacity because of automated vehicles could reduce future needs for new roads. However, induced travel demand resulting from enhanced road capacity, reduced GTC (generalized transport cost), and/or the proliferation of vehicle sharing systems and urban expansion may reduce or even cancel out or more than offset initial road capacity benefits. In the last case, additional road capacity may be required to accommodate new travel demand. Automated vehicles will also be likely to reduce demand for parking, thus, probably, fewer parking infrastructures will be required. Moreover, a reduced need for public transport services in some areas (especially those with low and medium densities) could also lead to public transport service cuts.

In this context, we can estimate that one of the main KPI of willingness to change infrastructure for municipalities will be the minimum of autonomous vehicles in the city in %, as a penetration rate.

Table 39: Local authorities: willingness to pay/invest in new or adapted infrastructures - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car		x	x
Rented car		x	x
Shared car/shuttle		x	x
Public transport		x	x
Helishuttle		x	x
Emergency vehicles		x	x

5.2.3 Data collection

The penetration rate of connected and autonomous vehicles could be included in the representative survey, as another indicators and acceptance factors.

The observation trial, as municipalities reports, could be also a good way to collect the penetration rate.

Table 40: Local authorities: willingness to pay/invest in new or adapted infrastructures - Overview over data collection possibilities

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x	x			

5.3 Local authorities, Businesses and Producers: Willingness to pay employee use

5.3.1 General concept indicators

According to Milakis et al. (2017), over 90% of crashes are attributed to human driver. Typical reasons include, in descending order, errors of recognition (e.g. inattention), decision (e.g. driving aggressively), performance (e.g. improper directional control), and non-performance (e.g. sleep). The advent of automated vehicles could significantly reduce traffic accidents attributed to the human driver by gradually removing the control from the driver’s hands, even if adaptive behavior (i.e. the adoption of riskier behavior because of over-reliance on the system) may have adverse effects on traffic safety. This can be achieved through advanced technologies applied to automated vehicles with respect to perception of the environment and motion planning, identification and avoidance of moving obstacles, longitudinal, lateral and intersection control, and automatic parking systems, for example.

Moreover, the introduction of automated vehicles might result in energy and emission benefits because of reduced congestion, more homogeneous traffic flows, reduced air resistance due to shorter headways, lighter vehicles (a result of enhanced safety), and less idling (a result of less congestion delays). Also, automated vehicles may require less powerful engines because high speeds and very rapid acceleration will not be needed for a large share of the fleet (e.g. shared automated vehicles). This could further improve the fuel efficiency and limit emissions. Grumert, Ma and Tapani (2015) reported a reduction in NOx and Hydrocarbon (HC) emissions from the application of a cooperative variable speed limit system that uses infrastructure-to-vehicle communication to attach individualized speed limits to each vehicle.

Emissions were found to decrease with higher penetration rates with this system. Wang, Chen, Ouyang and Li (2015) also found that a higher penetration rate of intelligent vehicles (i.e. vehicles equipped with their proposed longitudinal controller) in a congested platoon was associated with lower emissions of NOx. Moreover, Bose and Ioannou (2001) found, through using simulation and field experiments, that emissions could be reduced from 1.5% (NOx) to 60.6% (CO and CO2) during rapid acceleration transients with the presence of 10% ACC equipped vehicles. Choi and Bae (2013) compared CO2 emissions for lane changing of connected and manual vehicles. They found that connected vehicles can emit up to 7.1% less CO2 through changing from a faster to a slower lane and up to 11.8% less CO2 through changing from a slower to a faster lane.

5.3.2 Solution-specific indicators

The interest of organizations in having their employees use self-driving vehicles can thus be measured by several indicators, relating to safety, employee well-being, the reduction of greenhouse gas emissions, and the availability of sufficiently large vehicles.

- Estimated growth of agility for driven units (from 0 to 4).
- Estimated growth of the security of driven civil servants and employees (accidents number).
- Estimated reduced stress and fatigue of staff using vehicles (sick leaves number).
- Estimated reduction of fuel costs and CO2 emissions.

Table 41: Local authorities, Businesses and Producers: Willingness to pay employees use- Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	X	X	X
Rented car	X	X	X
Shared car/shuttle	X	X	X
Public transport	X	X	X
Helishuttle	X	X	X
Emergency vehicles	X	X	X

5.3.3 Data collection

Given the nature of the data to be collected and the target of the indicators, we believe that these data could be collected and cross-checked through Human Resources and employee surveys, observational trial and field experiments.

Table 42: Local authorities, Businesses and Producers: Willingness to pay employees use- Overview over data collection possibilities

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x	x	x		

5.4 Businesses and Producers: willingness to pay/invest and to adopt to increase efficiency

5.4.1 General concept indicators

Contrary to studies related to consumers, producers and public authorities (municipalities included), the studies related to the impact of CAVs and the willingness of businesses to invest, pay or adopt are scarce (Milakis, Van Arem and Van Wee, 2017).

In addition to scarcity, the speculations are mixed: on one hand, CAV solutions may bring significant economic benefits to businesses (including new jobs, higher profit etc.), but on the other hand it may also force businesses to reshape their business models in order to save their profit and avoid losses (in revenues and jobs) and bankrupts (Frey & Osborne, 2017; Milakis and al., 2017).

5.4.2 Solution-specific indicators

If OEM or producers are the first-order businesses concerned with CAV revolution, several other domains might be impacted as technology companies, service providers, transportation companies (trucking and freight), insurance companies, etc.

The improvement and acceleration of the use of CAVs can lead to a deep change in jobs type. Indeed the transportation and logistics sector could be replaced by computer automation within two decades. The study of (Frey & Osborne, 2017) states that this risk is very high, with a probability of 0.7 or more (on a scale of 1). Hearda et al. (2018) warns against the risk of unemployment for heavy and tractor-trailer truck drivers (around 63.000 job in the US).

Nevertheless, the trucking industry will be one of the most interested adopters as CAVs will offer greater efficiency, larger quantities of freight at lower costs, especially with platooning effects.

For now, insurances provide private people a coverage for accident cause by human error. However, with the use of CAV, the business model of the stakeholders could evolve to another insurance model that transfer the insurance responsibility to the OEM and infrastructure operators, and not the private user of the vehicle. This evolution could be compared to the current business model for cruise lines and shipping companies (McKinsey, 2015).

Thanks to CAV solutions, businesses might reduce dramatically the parking spaces needed for their employees and customers. This potential huge decrease might allow conversion of the parking space into revenue, commercial development (EIB, 2018). Some forecast in cities as Boston suggest up to 50% decrease in terms of parking spaces needed (World Economic Forum, 2018).

Thus, the KPIs are the following:

- Estimated time saved in business trips reduction (h./ year)
- Estimated value created by using CAV (Time saved, Place saved, €)
- Estimated reduction of fuel costs and CO2 emissions (n./ year)
- Number of employees up-skilled / re-skilled (n./ year)
- Estimated value of public grants for mobility services (in €)

Table 43: Businesses and Producers: willingness to pay/invest and to adopt to increase efficiency- Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car		X	X
Rented car		X	X
Shared car/shuttle		X	X
Public transport		X	X
Helishuttle		X	X
Emergency vehicles		X	X

5.4.3 Data collection

Given the nature of the data to be collected and the target of the indicators, we believe that these data could be collected through Executive and Human resources surveys.

Table 44: Businesses and Producers: willingness to pay/invest and to adopt to increase efficiency- Overview over data collection possibilities

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x				

5.5 Businesses and Producers: willingness to pay/invest for business opportunities

5.5.1 General concept indicators

The Boston Consulting Group forecast of 30 million autonomous or partially-autonomous vehicles to be sold in 2035, which seems over optimistic yet to a certain extend a proof that producers have a strong business interest in CAV adoption.

Indeed, several research and development Programmes are available for producers to invest in the Autonomous Vehicles.

The European Commission has launched in 2016 a new **High-Level Group for the automotive industry** (European Commission (GEAR 2030), 2017) called **GEAR 2030**: it gathers industrial representatives and European associations with EU institutions and national ministries. The objective is to address the challenges faced by the automotive industry and anticipate the future needed regulatory frameworks. A special attention is given to position the European industry as a technology leader and ensure its competitiveness on world markets.

A specific working group on “Highly automated and connected vehicles” has been set up, stressing the importance of the domain for the future of the European industry. The group is developing a roadmap with three pillars: Legal and policy issues; Coordination of financing support issues;

and Competitiveness/International aspects. The overall objective is to identify the possible actions at European level to ease and fasten the implementation of automated driving systems.

GEAR 2030 is now considering vehicles expected for the timeframe of 2030, which should include driverless vehicles (driver as a passenger). Large scale testing on open roads is considered a key tool to make progress on the technology, foster cooperation amongst the different actors and facilitate public acceptance.

GEAR 2030 is looking at possible additional tools that could be used to support future large-scale testing as well as the appropriate framework to ensure public confidence, in particular the certification approach, liability issues, automotive data issues and societal issues like the impact of automation on public transport, jobs or skills.

With regard to multi-modal transport, the European Commission is also developing, in close cooperation with representatives of the EU Member States and stakeholders from industry, academia, and national authorities, the STRIA roadmap for short, medium and long-term research and innovation initiatives and actions in the area of Connected and Automated Transport (CAT).

Some other initiatives aim to coordinate consensus-building across stakeholders for sound and harmonized deployment of CAD in Europe (CARTRE, ARCADE), or to create a comprehensive cross-sectorial roadmap describing the pathways for an accelerated proliferation of safe and secure high-level CAD by 2030 in Europe (Jörg Dubbert, Wilsch, Zachäus, & Meyer, 2019) (SCOUT).

The involvement of car manufacturers / producers in these initiatives are the proof of the willingness of producers to pay / invest in the topic.

Moreover, according to an EIB report (2018), Technology companies, which are data-centered, will play a great role with CAV innovations. Despite big players such as Google, Apple, or Nvidia, many SMEs can benefit from the CAV revolution.

As one of the most visible CAV business for the public, service providers as Lyft or Uber are and will greatly impact the mobility of the future (car-sharing, ride-sharing modalities, etc.). However, the job creation/destruction ratio is still uncertain (i.e. taxi driver might no longer exist but data analyst used to consider mobility will play a vital role in many companies).

Thanks to an increasing maturity of CAVs solutions, the accident frequency will diminish as the number of deaths, injuries, material damage. Therefore, car repair business but also insurance will have to rethink their business models.

If businesses could be leaders and invest in CAV's R&D projects, they will only keep their efforts in case of strong national or international public support (in terms of finance and legislation).

As highlighted by an EIB report, there is an urgent need to "align and amend European policies and legislation on autonomous driving and push for a technology-friendly testing environment" (EIB, 2018).

5.5.2 Solution-specific indicators

The interest of businesses and producers in investing in CAV can thus be measured by several indicators:

- Number of internal RDI project related to CAV
- Number of external projects related to CAV
- New established businesses (n./ year)
- New job created (n./ year)
- New product / services created (n / year)

Table 45: Businesses and Producers: willingness to pay/invest and to adopt for business opportunities- Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car		x	x
Rented car		x	x
Shared car/shuttle		x	x
Public transport		x	x
Helishuttle		x	x
Emergency vehicles		x	x

5.5.3 Data collection

Given the nature of the data to be collected and the target of the indicators, we believe that these data could be collected through Executive and Business Department surveys.

Table 46: Businesses and Producers: willingness to pay/invest and to adopt for business opportunities - Overview over data collection possibilities

Data Collection	**Representative Survey**	**Observational trial**	**Experimental field trial**	**VR / Home system**	**Computational simulation**
Possible inclusion	x				

6 Indicators of society level acceptance

6.1 Mobility and transport network

6.1.1 Concept

Several specific KPIs were identified to measure the factors of mobility and transport network (Alessandrini, Campagna, Site, Filippi, & Persia, 2015b; Burns, 2013; Greenblatt & Shaheen, 2015). In the report “Research on the Impacts of Connected and Autonomous Vehicles (CAVs) on Traffic Flow” by Atkins Ltd 2016), based on the microsimulation software package, VISSIM 8, it has been tested the impact of different car-following behaviour, different lane changing and gap acceptance behaviour, different profiles of acceleration and deceleration, connectivity to represent the better provision of information; and different levels of CAV penetration in the vehicle fleet. The following indicators have been used to measure the different impacts, and will be exploited within the PAsCAL project.

6.1.2 Average journey time per road-km and journey time variability

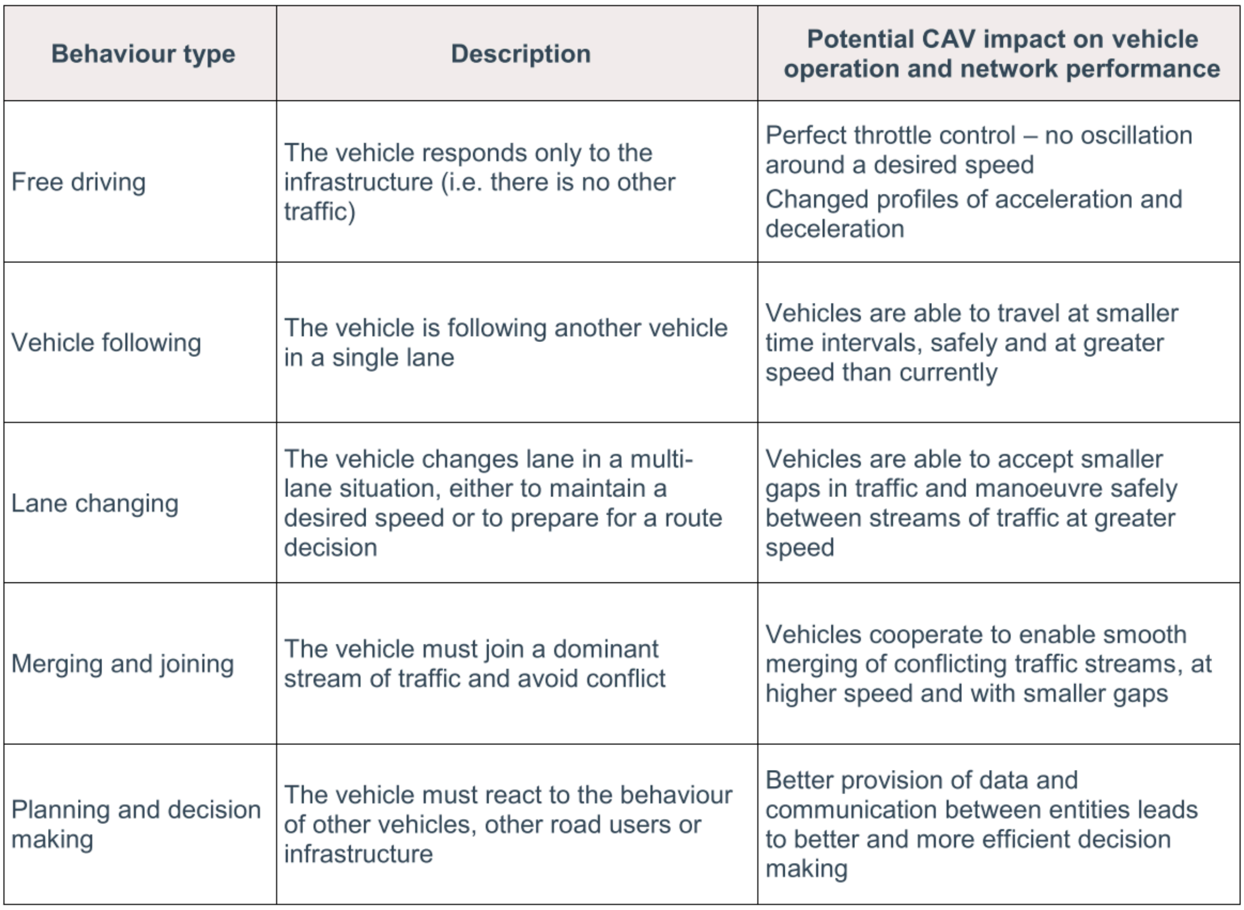
In particular, the simulations in VISSIM 8 show a much greater improvement at low (25%) levels of CAV penetration, with a 12% improvement in delay, 21% improvement in journey times and a near 80% improvement in journey time. At 100% penetration of CAVs, reductions in journey times are a little over 4%, yet variability is reduced by around 50%.

In a synthesis on the impact of autonomous vehicles on society and the economy, Fagnant and Kockelman (2015) underline that the persons with high values of travel time and/or parking costs may find the CAV technology a worthwhile investment. Only at the $10,000 (€ 9,100) added price does the technology become a realistic investment for many, with $1 (€ 0.91) per hour time value savings and $1 (€ 0.91) daily parking cost savings generating an 11% rate of return for AV owners.

6.1.3 Network capacity, traffic flow and capability change

Based on the European project CityMobil2, Alessandrini, Campagna, Site, Filippi and Persia (2015) underline that cars are used only for short periods at a time and thus stay parked and unused for most of the day. The total number of owned cars in a city TH should be used in the peak hour only 11% on average. In a city with shared automated cars, the total number of cars needed to provide car-based mobility services are the number of owned cars, a fraction of TH, plus the CAVs needed at the peak hour. For each 10% reduction in the number of cars owned, there should be only 11% of CAVs, but because the people willing to give up their own cars are modest users, the need for automated cars will be much smaller. The use of the CAVs fleet should be optimized to increase the service and reduce the idle time. Moreover, CAVs should save space not only by reducing the number of parked vehicles, but also by reducing the space required for parking them. Thus, storing vehicles should require one quarter of the space per vehicle currently required in a conventional garage.

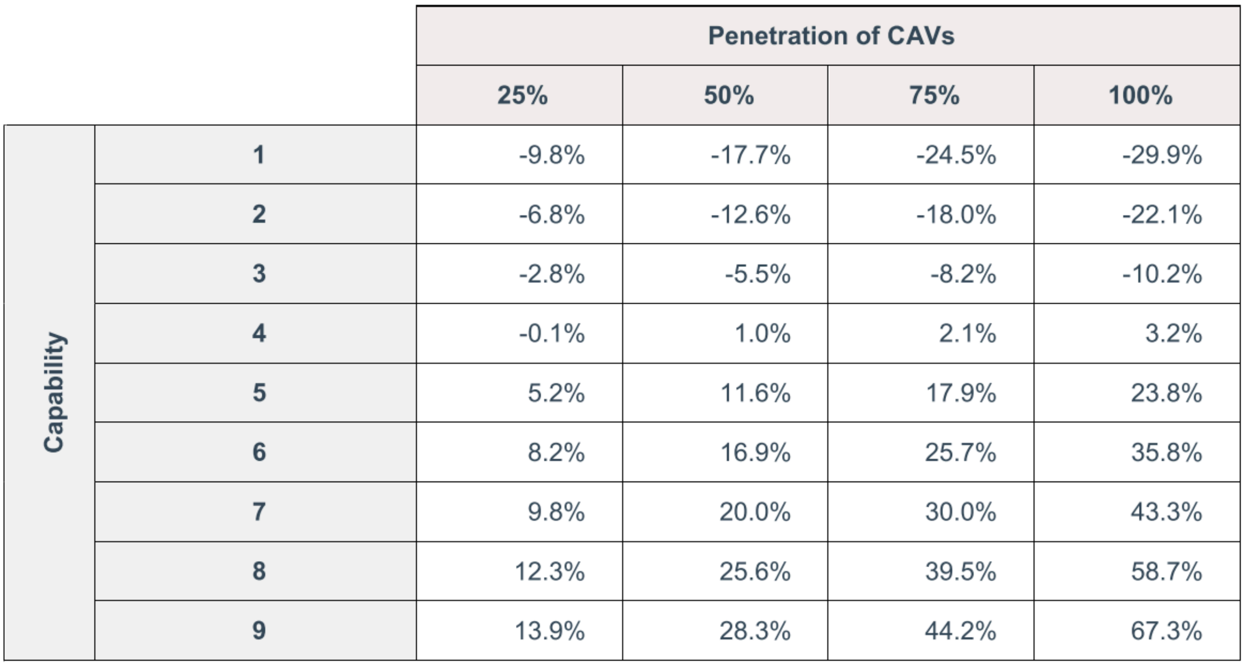
According to Atkins (2016), capacity is defined as the maximum sustainable flow of traffic passing in a single hour under favourable road and traffic conditions. Thus, technological advancements associated with connectivity and autonomy have the capability to change the way vehicles behave to the benefit of traffic flow and road capacity (Figure 21).



Behaviour type	Description	Potential CAV impact on vehicle operation and network performance
Free driving	The vehicle responds only to the infrastructure (i.e. there is no other traffic)	Perfect throttle control – no oscillation around a desired speed Changed profiles of acceleration and deceleration
Vehicle following	The vehicle is following another vehicle in a single lane	Vehicles are able to travel at smaller time intervals, safely and at greater speed than currently
Lane changing	The vehicle changes lane in a multi-lane situation, either to maintain a desired speed or to prepare for a route decision	Vehicles are able to accept smaller gaps in traffic and manoeuvre safely between streams of traffic at greater speed
Merging and joining	The vehicle must join a dominant stream of traffic and avoid conflict	Vehicles cooperate to enable smooth merging of conflicting traffic streams, at higher speed and with smaller gaps
Planning and decision making	The vehicle must react to the behaviour of other vehicles, other road users or infrastructure	Better provision of data and communication between entities leads to better and more efficient decision making

Figure 21: Example mechanisms of CAV impact under different road network situations Behaviour.

Extracted from the Atkins' report, Figure 22 shows the capacity impact of varying capability and penetration17. Capacity for each combination of capability and penetration is compared to the base situation. The results show greater penetration of increasingly capable CAVs resulting in greater capacity. Conversely, where CAVs are more cautious than the existing vehicle fleet, a decrease in capacity is observed.



		Penetration of CAVs			
		25%	50%	75%	100%
Capability	1	-9.8%	-17.7%	-24.5%	-29.9%
	2	-6.8%	-12.6%	-18.0%	-22.1%
	3	-2.8%	-5.5%	-8.2%	-10.2%
	4	-0.1%	1.0%	2.1%	3.2%
	5	5.2%	11.6%	17.9%	23.8%
	6	8.2%	16.9%	25.7%	35.8%
	7	9.8%	20.0%	30.0%	43.3%
	8	12.3%	25.6%	39.5%	58.7%
	9	13.9%	28.3%	44.2%	67.3%

Figure 22: Model capacity impact

6.1.4 Average junction delay

Another important indicator is the junction delay (Azimi, Bhatia, Rajkumar, & Mudalige, 2014; Furukawa, Saito, Tokunaga, & Kiyohara, 2018; Hausknecht, Au, & Stone, 2011). Atkins Ltd measured several levels of junction performance based on the penetration rate of VACs. Starting from a base situation, the results show that the average delay (in seconds) decrease as the penetration rate is high, from 24.5 seconds (0% penetration) to 22.5% for a 100% penetration rate. These results are recorded in situations of high demand (peak). Ilgin Guler, Menendez and Meier (2014) also simulated the efficiency of intersections using CAV. Indeed, the results of the simulations show using information from connected vehicles to better adapt the traffic signal has proven to be very valuable. Increases in the penetration rate from 0% up to 60% can significantly reduce the average delay (in low demand scenarios a decrease in delay of up to 60% can be observed). After a penetration rate of 60%, while the delays continue to decrease, the rate of reduction decreases and the marginal value of information from communication technologies diminishes. Overall, it was observed that CAVs could significantly improve the operation of traffic at signalised intersections.

In another study, Furukawa et al. (2018) looked at T-shaped intersections and the optimization of vehicle insertions as a function of the degree of autonomy. Simulations show that in a case of full autonomy, the time between vehicles can be reduced to 0.71 seconds without causing congestion at intersections, while it is 1.8 seconds in the case of non-autonomous vehicles.

6.1.5 Total kilometres travelled

It is expected that the vehicle-kilometres travelled (VKT) will increase of 3% by 2035 (Trommer et al., 2016), with a maximum of 9%. Regarding Trommer et al. (2016) the main driver behind the overall increase in distance travelled consists of new groups of users who have not had access to a car before. This includes disabled individuals, elderly people, teenagers, and children. Furthermore, people who had formerly been regular car passengers now more often ‘drive’ themselves. As a result of the effects above, the increase in vehicle-kilometres travelled is expected to be 3–9% compared to a case without any automatisation in the private car fleet.

On their side, Fagnant and Kockelman (2018) found that dynamic ridesharing (DRS) would reduce the vehicle-kilometres travelled by 7% and the waiting time by 25%.

6.1.6 Transport mode by car/public transport and car availability

The transport mode and sustainable transportation systems play a vital role in the efficiency of mobility and transport network. Several studies speak about shared autonomous vehicles, as an attractive mobility option for elderly travellers and for individuals, who currently do not have access to private transportation (Krueger, Rashidi, & Rose, 2016). Trommer et al. (2016) examine the potential impact of autonomous driving on the future of mobility behaviour, focusing primary on passenger cars and levels of automation sufficient to permit drivers to undertake other activities while travelling in an autonomous car. Their study predicts an increase in the number of autonomous vehicles available (up to 13% in Germany and the USA), and a decrease in the number of traditional vehicles (from 82% to 71% in Germany and from 79% to 70% in the USA).

Pakusch, Stevens and Bossauer (2018) carried out a questionnaire on 302 German participants to find out which modes of transport would be preferred in the future. They were asked to select their preference from peers of transport modes, including Public transport, Automated carsharing, Carsharing, Automated Car and Car. The participants confirm that the traditional private car has a slightly higher total utility than the autonomous private car, so that 59.6% of the participants still prefer the traditional version. The authors explain that the privately-owned car being the most popular travel mode today affects the preferences for future travel mode choices. As travel mode choice is strongly influenced by socialization and habits, users familiar with using a private car considerably more often choose the private car to be the most preferred travel mode in the future too. When directly comparing the preferences for fully autonomous modes for either the private car or carsharing, it is also noticeable that 58.9% of the respondents prefer the fully automated version for carsharing, compared to only 40.4% for private cars. This significant difference in user preferences indicates that the acceptance of full automation depends on the increase in total utility of the respective traffic mode. From the user's point of view, full automation in the private car segment therefore brings comparatively minor improvements, while it greatly increases the benefits and thus the attractiveness of carsharing.

6.1.7 Critical density and maximum flow

Based on a microscopic traffic simulation, Lu et al. (2019) investigate the impact of CAVs on urban road network capacity. The results show that the capacity is increasing quasi-linearly with higher AVs penetration for both grid networks and real- world network. In the grid network, the maximum flow increases by 16.01% considering the 100% AVs penetration scenario with only conventional vehicles. Another research on CAVs and traffic flow (Olia, Razavi, Abdulhai, & Abdelgawad, 2018) assesses the impact of AVs on highway capacity. The results indicate that a maximum lane capacity of 6,450 vph (vehicles per hour) per lane is achievable If all vehicles are cooperative AVs. Undermixed traffic conditions, cooperative AVs can significantly increase highway capacity when their market penetration is higher than 30%. The introduction of cooperative AVs at a low market penetration (less than 30%) results in the least capacity benefits; in this case, the vehicles are scattered across all lanes of a multi-lane highway and thus lack frequent opportunities for one cooperative AV to follow another cooperative AV.

Table 47: Summary of the KPIs for mobility and transport network

KPIs	Units
Number of trips	n.
Average journey time per road-km	s
Total kilometres travelled	km
Transport mode by car/ public transport	%
Journey time variability	%
Car availability	%
Critical density	n./ km
Network capability change	%
Average junction delay	%
Traffic flow	n./ h
Peak period along a route	Specific time
Maximum flow	n./ h

In the table below, several CAV solutions (owned car, rented car, shared car/shuttle, public transport, helishuttle, emergency vehicles) are positioned according to their possible degree of autonomy (level 3, 4 or 5 – full autonomy). The check boxes correspond to the indicators presented in this section, which can be applied to each of these solutions.

Table 48: Mobility and transport network - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles	x	x	x

6.1.8 Data collection in PAsCAL

The table below shows how the indicators, presented in this section, can be collected.

Table 49: Mobility and transport network - Overview over data collection possibilities

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x	x	x		x

6.2 Safety and security at societal level

6.2.1 General concept and indicators for specific solutions

Lin, Wang and Guo (2016) underline that more than 90% of vehicle crashes are at least partially a result of human error, which means driver behavior is the most important factor for traffic safety. Thus, by greatly reducing the chance for human error, further automation is expected to save more lives. According to Goodall (2014), to be considered safer than a human driver with 99% confidence, an automated passenger vehicle would need to travel 1.1 million kilometres without crashing and 482 million kilometres without a fatal crash.

In the same way, cyber security could have another impact on public acceptance (Kyriakidis, Happee, & De Winter, 2015). According to Lin, Wang and Guo (2016), the most daunting risk is the possibility that terrorists could hack into AV driving systems and cause accidents for targeted individuals or large numbers of people. Hackers could manipulate car locking systems, sensors, engine controls, brake functions, and others by attacking through back-end, maintenance, or third-party systems.

The collision between CAVs themselves is another part of security and safety. For Goodall (2014), the risks of collision could be reduced, even if fully-automated vehicle will have to interact with human drivers, pedestrians, bicyclists, motorcyclists, and trains. Even an automated-only zone would encounter debris, wildlife, and inclement weather.

Innamaa and Kuisma (2018) measure safety as number of fatalities, injuries or property damage for vehicle occupants and other road users. Other road users may include pedestrians, bicyclists, slow- moving vehicles, construction workers and first respondents. They use several indicators regarding the level of automation (Table 50).

Table 50: Average ratings for the safety KPIs for different level of automation (blue color from original documentation)

KPI	SAE 1-2		SAE 3		SAE 4-5	
	Rating	N	Rating	N	Rating	N
Number of crashes (distinguishing property damage, and crashes with injuries and fatalities), in total and per 100 million km or miles	5.45	11	5.67	15	6.00	14
Number of instances where the driver must take manual control / 1000 km or miles	5.40	10	5.27	15	5.43	14
Number of conflicts encountered where time-to-collision (TTC) is less than a pre-determined threshold / 100 million km or miles	5.18	11	5.60	15	5.07	14
Number of instances with hard braking (high deceleration) / 1000 km or miles	5.45	11	5.07	15	5.15	13
Number of false positives / 1000 km or miles, i.e. instances where the vehicle takes unnecessary collision avoidance action	5.60	10	4.93	15	5.00	14
Number of instances rated by a human as being of increased risk or not correctly handled by the automated vehicle / 1000 km or miles	4.90	10	5.36	14	5.00	14
Proportion of time when time-to-collision (TTC) is less than a pre-determined threshold	4.82	11	5.07	15	5.07	14
Distribution of TTC at brake onsets	5.09	11	4.77	13	4.86	14
Number of selected traffic violations / 1000 km or miles of driving	4.91	11	4.79	14	5.00	13

Table 51: KPIs for safety and security at societal level.

KPIs	Units
Number of conflicts	n./million km
Number of injuries	n./ million km
Number of fatalities	n./ million km
Number of instances where the driver must take manual control per 1000 km or miles	n./ km
Number of conflicts encountered where time-to-collision (TTC) is less than a pre-determined threshold per 100 million km or miles	n./ km
Number of attacks of the CAV platforms by hackers	n./ year
Safety distance	m

In the table below, several CAV solutions (owned car, rented car, shared car/shuttle, public transport, helishuttle, emergency vehicles) are positioned according to their possible degree of autonomy (level 3, 4 or 5 – full autonomy). The check boxes correspond to the indicators presented in this section, which can be applied to each of these solutions.

Table 52: Safety and security at societal level - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	X	X	X
Rented car	X	X	X
Shared car/shuttle	X	X	X
Public transport	X	X	X
Helishuttle	X	X	X
Emergency vehicles	X	X	X

6.2.2 Data collection in PAsCAL

The table below shows how the indicators, presented in this section, can be collected.

Table 53: Safety and security at societal level - Overview over data collection possibilities

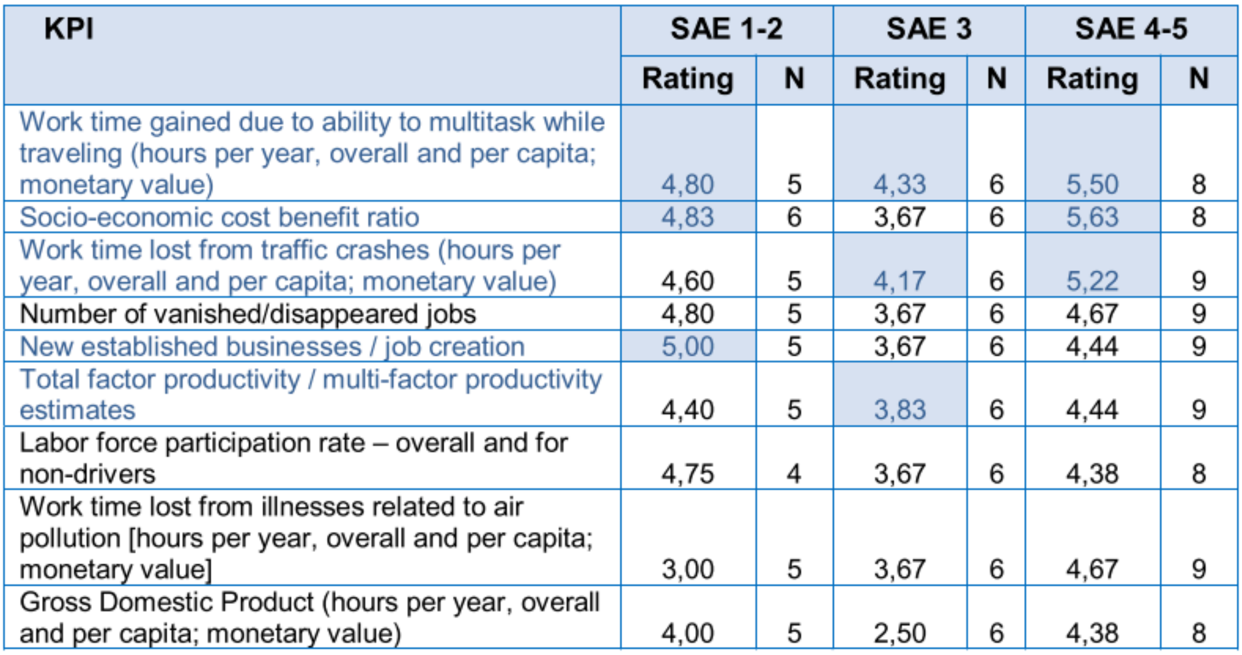
Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x	x	x		x

6.3 Socio-economic impacts

6.3.1 General concept and indicators for specific solutions

In their report, Innamaa and Kuisma (2018) expose a survey which was designed to investigate views on the importance of different key performance indicator (KPIs) for expressing the impact of automation in road transportation in several impact areas. Regarding the socio-economic impacts, it concerns improved safety, use of time, freight movement, travel options (for motorists and non-motorists), public health, land use and effects of changed emissions (including climate change) will have longer-term economic impacts. Automation may also have substantial impact on labour markets and industries (Table 54).

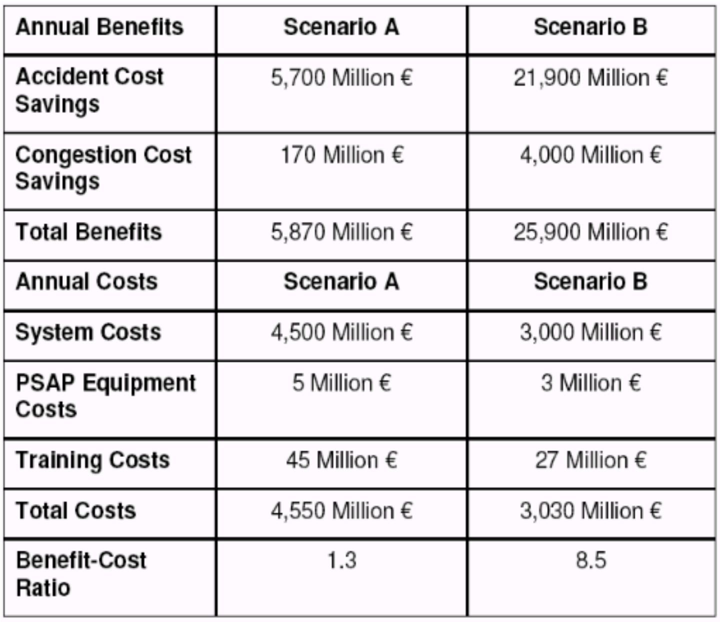
Table 54: Average ratings for the economic impact KPIs for different level of automation KPI (blue color from original documentation)



KPI	SAE 1-2		SAE 3		SAE 4-5	
	Rating	N	Rating	N	Rating	N
Work time gained due to ability to multitask while traveling (hours per year, overall and per capita; monetary value)	4,80	5	4,33	6	5,50	8
Socio-economic cost benefit ratio	4,83	6	3,67	6	5,63	8
Work time lost from traffic crashes (hours per year, overall and per capita; monetary value)	4,60	5	4,17	6	5,22	9
Number of vanished/disappeared jobs	4,80	5	3,67	6	4,67	9
New established businesses / job creation	5,00	5	3,67	6	4,44	9
Total factor productivity / multi-factor productivity estimates	4,40	5	3,83	6	4,44	9
Labor force participation rate – overall and for non-drivers	4,75	4	3,67	6	4,38	8
Work time lost from illnesses related to air pollution [hours per year, overall and per capita; monetary value]	3,00	5	3,67	6	4,67	9
Gross Domestic Product (hours per year, overall and per capita; monetary value)	4,00	5	2,50	6	4,38	8

A balance between costs and benefits has been calculated by Forrest and Konca (2007) and the eCall European project, which aims implementing a special emergency system on every car. This system automatically triggers an emergency call if the vehicle is involved in a serious accident. According to the analysis done, if an eCall system was installed in every vehicle, deaths in traffic accidents could be reduced by up to 15 percent, reducing the human toll, saving up to € 22 billion in social costs per year in the EU. This study also states that eCall could reduce congestion times up to 20 percent, saving an extra € 4 billion (Table 55).

Table 55: eCall benefit-cost analysis



Annual Benefits	**Scenario A**	**Scenario B**
Accident Cost Savings	5,700 Million €	21,900 Million €
Congestion Cost Savings	170 Million €	4,000 Million €
Total Benefits	5,870 Million €	25,900 Million €
Annual Costs	**Scenario A**	**Scenario B**
System Costs	4,500 Million €	3,000 Million €
PSAP Equipment Costs	5 Million €	3 Million €
Training Costs	45 Million €	27 Million €
Total Costs	4,550 Million €	3,030 Million €
Benefit-Cost Ratio	1.3	8.5

Another indicator have been extracted from Geurs and van Wee (2004) on the socio-economic impact of accessibility, and Kyriakidis, Happee and De Winter (2015) in the large survey on 5,000 respondents. The last authors found that people were inclined to pay the most, on average, for fully automated driving, whereas the step from partially to highly automated driving was not considered worth extra money. Thus, they conclude there is a market for automated driving technologies, but one has to acknowledge that a part of the population is reluctant against such technology. At the same time, there is a fair part of the population who will enjoy fully automated driving, and about 5% would be willing to pay even more than $30,000 (€27,162) to purchase it.

Table 56: KPIs for socio-economic impacts

KPIs	Units
Work time gained due to ability to multitask while travelling	Hours/ year
Work time lost from traffic crashes	Hours/year
Socio-economic cost benefit ratio	%
Growth of the automotive industry	%/ year
Growth of transport services	%/ year
New established businesses	n./ year
Number of lanes	n.
Operation and maintenance cost for digital infrastructure	€ / year
Operating costs for the deployed system	€ / year
Cost for infrastructure renewal	€ / year

In the table below, several CAV solutions (owned car, rented car, shared car/shuttle, public transport, helishuttle, emergency vehicles) are positioned according to their possible degree of autonomy (level 3, 4 or 5 – full autonomy). The check boxes correspond to the indicators presented in this section, which can be applied to each of these solutions.

Table 57: *Socio-economic impacts - Overview over solutions*

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles	x	x	x

6.3.2 Data collection in PAsCAL

The table below shows how the indicators, presented in this section, can be collected.

Table 58: Socio-economic impacts - Overview over data collection possibilities.

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x	x			

6.4 Quality of life

6.4.1 General concept and indicators for specific solutions

Quality of life (QOL) covers numerous aspects for citizens (Burckhardt & Anderson, 2003). Innamaa and Kuisma (2018) underline that could include personal mobility, which covers journey quality (comfort, use potential of in-vehicle time), travel time, cost; and whether the travel option is available to someone (e.g., a non- motorist), and equity and accessibility considerations.

Geurs and van Wee (2004) speak about the accessibility and its components in terms of new services accessibilities for citizens. That is included the amount, quality and spatial distribution opportunities supplied at each destination (jobs, shops, health, social and recreational facilities, etc.), also the demand for these opportunities at origin locations (e.g. where inhabitants live), and the confrontation of supply of and demand for opportunities, which may result in competition for activities with restricted capacity such as job and school vacancies and hospital beds.

The EQ-5D-5L survey (van Reenen et al., 2019) descriptive system comprises five dimensions, each describing a different aspect of quality of life and health: mobility, self-care, usual activities, pain and discomfort, anxiety and depression. Each dimension has three response levels of severity: no problems, some problems, extreme problems.

Table 59: KPIs for quality of life

KPIs	Units
Number of trips per week	n./week
Total time spent travelling per week	Hours/week
Number of parking slots	n/km
Social isolation	%
Proportion of people with improved access to health services	%
Total mileage travelled by active modes of transportation	km

In the table below, several CAV solutions (owned car, rented car, shared car/shuttle, public transport, helishuttle, emergency vehicles) are positioned according to their possible degree of autonomy (level 3, 4 or 5 – full autonomy). The check boxes correspond to the indicators presented in this section, which can be applied to each of these solutions.

Table 60: Quality of life - Overview over solutions.

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	X	X	X
Rented car	X	X	X
Shared car/shuttle	X	X	X
Public transport	X	X	X
Helishuttle	X	X	X
Emergency vehicles	X	X	X

6.4.2 Data collection in PAsCAL

The table below shows how the indicators, presented in this section, can be collected.

Table 61: Quality of life - Overview over data collection possibilities.

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x	x			

6.5 Public awareness

6.5.1 General concept and indicators for specific solutions

Public awareness about CAVs may vary depending on the audience surveyed. In a survey, Shergold, Wilson and Parkhurst (2016) note that public awareness of CAVs is generally not highly developed and is probably not evenly developed across the population. The attitudinal findings may as much be reflecting uncertainties about CAVs, as much as resistance to them. In a survey of 1,533 respondents aged 18+ in the US, UK and Australia, the authors found that older respondents (no clarification of age groups) were less interested in having self-driving technology and less willing to ride in self-driving vehicles. Older respondents were also less optimistic about the potential benefits of these technologies. They were less optimistic that self-driving vehicles would reduce traffic congestion, shorten travel times, and lower insurance rates, and overall were more concerned about self-driving vehicles. In another survey, on 1,070 older drivers aged 60+ and 8 in-depth interviews with older drivers in Australia. Participants generally had very poor knowledge and awareness of various new safety technologies, e.g. blind spot warning and lane departure warning, yet they were open to the idea of having in-vehicle safety technologies and reported that they would feel safer if these technologies were present in their car. However, participants were less open to the idea of autonomous vehicles, as they believed that safety features and technologies should be there as a 'just in case' measure instead of replacing driver skill. Many participants were opposed to too much reliance on technology to do the driving.

Schoettle, Brandon and Sivak (2014) were interested in the awareness and feeling of citizens to be concerned by different themes related to autonomous and connected vehicles. For example, one of the results was the higher the level of autonomous-vehicle technology installed on the respondents' current vehicles, the more likely respondents were to expect crash-reduction benefits, less traffic congestion, shorter travel time, lower vehicle emissions, and better fuel economy. Those with higher levels of autonomous-vehicle technology were more likely to express concern about system security and data privacy. Higher levels of autonomous-vehicle technology on their current vehicles also corresponded with increased interest in having self-driving-technology on their vehicle, and with being less likely to say that they would not ride in self-driving vehicles.

Table 62: KPIs for public awareness.

KPIs	Units
Percentage of awareness in CAV technology	%
Percentage of public awareness in restrictions by their mobility	%
Percentage of awareness in stress release if CAVs	%
Percentage of awareness in conveniences for disability	%

In the table below, several CAV solutions (owned car, rented car, shared car/shuttle, public transport, helishuttle, emergency vehicles) are positioned according to their possible degree of autonomy (level 3, 4 or 5 – full autonomy). The check boxes correspond to the indicators presented in this section, which can be applied to each of these solutions.

Table 63: Public awareness - Overview over solutions

CAV Solutions	**Level 3 (conditional automation)**	**Level 4 (high automation)**	**Level 5 (full automation)**
Owned car	x	x	x
Rented car	x	x	x
Shared car/shuttle	x	x	x
Public transport	x	x	x
Helishuttle	x	x	x
Emergency vehicles	x	x	x

6.5.2 Data collection in PAsCAL

The table below shows how the indicators, presented in this section, can be collected.

Table 64: Public Awareness - Overview over data collection possibilities.

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x	x	x		x

6.6 Public acceptance

6.6.1 General concept and indicators for specific solutions

In a survey on the adoption of CAVs by American citizen in the long term, Bansal and Kockelman (2017) measured the public acceptance and showed that 54.4% of the respondents perceived CAVs as a useful advancement in transportation, but 58.4% were scared of them. Only 19.5% of respondents will be comfortable sending a CAV driving on its own, but 41.4% of the respondents agreed with the statement that AVs will be omnipresent in the future. Around 49% of the respondents thought that CAVs will function reliably, while 44% believed the idea of CAVs is not realistic.

Elbanhawi, Simic and Jazar (2015) measured the perceived comfort in CAVs, which it could be considered as an inhibitor of acceptance, such as safety, cyber security, personal aspects, social aspects and legal liability. The passengers' comfort is influenced by several indicators: air quality, sound and noise, temperature and vibrations.

Koul and Eydgahi (2018) measured the technology acceptance of CAVs using TAM model (Davis, Bagozzi, & Warshaw, 1989). Thus, the intention to use CAV was measured through the perceived usefulness of CAV, the perceived ease of use of CAV, and additional variables (as age, gender, ethnicity, etc.). Thus, the study revealed as the perception of usefulness associated with DCT increased, the intentions of potential consumers to use DC strongly increased. Also, as the perception of ease of use associated with DCT increased, the intentions of the potential consumers to use DC increased.

Table 65: KPIs for public acceptance

KPIs	Units
Frequency of using CAV functions	n./ month
Requirement of attention for driving (time percentage)	%
Perception of reliability (percentage of public)	%
Perceived usefulness (percentage of public)	%
Perceived comfort (percentage of public)	%
Perceived ease of use (percentage of public)	%
Willingness to share data (percentage of public)	%
Perceived control (percentage of public)	%
Perceived safety (percentage of public)	%
Perceived data security (percentage of public)	%
Perceived workload	h/ week
Perceived trust (percentage of public)	%
Intended use (percentage of public)	%

In the table below, several CAV solutions (owned car, rented car, shared car/shuttle, public transport, helishuttle, emergency vehicles) are positioned according to their possible degree of autonomy (level 3, 4 or 5 – full autonomy). The check boxes correspond to the indicators presented in this section, which can be applied to each of these solutions.

Table 66: Public acceptance - Overview over solutions

CAV Solutions	Level 3 (conditional automation)	Level 4 (high automation)	Level 5 (full automation)
Owned car	X	X	X
Rented car	X	X	X
Shared car/shuttle	X	X	X
Public transport	X	X	X
Helishuttle	X	X	X
Emergency vehicles	X	X	X

6.6.2 Data collection in PAsCAL

The table below shows how the indicators, presented in this section, can be collected.

Table 67: Public acceptance - Overview over data collection possibilities.

Data Collection	Representative Survey	Observational trial	Experimental field trial	VR / Home system	Computational simulation
Possible inclusion	x	x	x		

7 Summary and conclusion

The PAsCAL evaluation framework and its associated indicators as presented here provide an extensive overview for PAsCAL project partners, in particular trial partners, over available indicators that can be implemented across research to assess the human and societal impacts of connected and automated vehicle developments. Its goal is to help PAsCAL partners to work towards harmonisation of the different surveys, experiments, simulators and pilots, with the aim to achieve results that can be comparable and understandable across data collection methodologies.

With expectations regarding CAVs high, and benefits and barriers widely discussed across research, the present framework can aid in gaining a better understanding what already exists and how it can be maximised for the PAsCAL project outcomes. With results from data collection that adopt or adapt the here presented indicators, a better interpretable picture should emerge that will allow a better steering of CAV development towards goals that interest both individual users and society.

Despite the thoroughness of this overview, this document can only be a first step: thus, the present version of the indicator analysis is the very first definition and is only meant as a starting point before further analysis is completed, and the consortium continues developing and refining the here proposed methodologies. In the course of the PAsCAL project, the document will be improved from feedback and novel insights, and in addition updated to ensure maximum impact.

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