Description of user needs

Deliverable Number	D1.1
Deliverable Type	R – Document, Report
Dissemination Level	PU (Public)
Author(s)	Miguel Ángel Sotelo/UAH
Document Version & Status	V2.0/Final

Project Acronym	HEIDI
Project Title	Holistic and adaptivE Interface Design for human-technology Interactions
Grant Agreement Number	101069538
Project Coordinator	Virtual Vehicle Research GmbH
Project Website	www.heidi-project.eu

HEIDI has received funding from the European Union's Horizon Europe research and innovation programme under Grant Agreement No. 101069538.

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Change History

Version	Date	Name/Organisation	Description
0.1	2022-09-21	UAH	Preliminary structure and content of D1.1.
0.2	2022-10-04	UAH	Content added in sections 1, 2, and 4.
0.3	2022-10-07	UAH	Content added in sections 1, 2, and 4.
0.4	2022-10-14	UAH	Contributions from VIF and HRI are added.
1.0	2022-11-07	UAH	Preliminary final version with contributions from all partners included.
1.1	2022-11-09	UAH	Revised preliminary final version.
1.2	2022-11-10	UAH	Preliminary final version shared with HEIDI consortium.
2.0	2022-11-22	UAH	Final, reviewed version.

Documentation of Delayed Submission

Planned Date	2022-11-30
Actual Date	2022-11-23
Reasons causing the delay	No delay
Effects on follow-up activities and other WPs/tasks	
Mitigation measures	

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1. Executive Summary

The scope of this deliverable is to define the road user's types and the different road user's needs in order to maximize safety and comfort while guaranteeing understandability and smooth interactions with automated vehicles with SAE (Society of Automation Engineers) levels of Driving Automation [1] from 1 to 5. Passengers of either private or public transport vehicles are not considered in the scope of this project, and consequently not considered in this document, as they are neither in control nor responsible for road safety, i.e., they are not targeted by the HEIDI cooperative fluid HMI (Human-Machine Interface) to be developed in the context of this project. This goal is aligned with the four HEIDI objectives (#1, #2, #3, and #4).

A detailed taxonomy of user types has been conducted by considering Vulnerable Road Users (VRUs), ego-driver (i.e., driver of the automated vehicle), and external drivers (i.e., drivers of other vehicles in the vicinity of the ego-vehicle). On top of that, users with some type of disability or reduced capacity (attention) have also been considered as a special case to take into account. In this regard, the HEIDI project considers older pedestrians, children, older drivers, pedestrians walking on crutches or walkers, wheelchair users, visually impaired pedestrians, distracted drivers, and distracted pedestrians (pedestrians talking to other pedestrians or using their cell phones while crossing or while waiting to cross). In addition, HEIDI studies the needs of groups of pedestrians, while accounting for their group dynamics. By doing so, the HEIDI project proposes to go beyond the state of the art by considering road users with disabilities and/or reduced capacity, including groups of users, that have never been considered so far in previous projects or developments dealing with interactions with automated vehicles.

HEIDI has defined the user needs for all these types of road users, as described in this deliverable, with a special focus on the interactions with partially automated (ADAS-assisted) vehicles. The user needs include, but are not limited to, factors such as safety, optimised efficiency of mobility, smooth, intuitive, and non-distractive interaction with automated vehicles, reduced mental load for drivers in the long term, improved perception of comfort, and enhanced respect towards all road users, especially those with some kind of disabilities or reduced capacity. The analysis of the user needs provides the basis for the further design and development of the internal HMI (iHMI) in WP2, the external HMI (eHMI) in WP3, and the HEIDI cooperative fluid HMI in WP4. The links and connections between the user needs and the different work packages have been properly established. The joint definition of user types and user needs in this deliverable (D1.1) sets the ground for the development of the most advanced HMI system in the state of the art, capable of simultaneously interacting with VRUs, other drivers, and the ego-driver, in a synchronized and effective manner. Moreover, requirements will be derived to design a cooperative HMI that can compensate reduced user ability (age, distraction) to still fulfil the identified user needs, according to user type (driver, VRU) and automation level.

Keywords: road user types, road user needs, requirements

2. Objectives

The main goal of this deliverable is to define the road user's types and the different road user's needs in order to maximize safety and comfort while guaranteeing understandability and smooth interactions with automated vehicles, with special focus on SAE levels from 1 to 3. Passengers of either private or public transport vehicles are not considered in the scope of this project, and consequently not considered in this document, as they are neither in control nor responsible for road safety, i.e., they are not targeted by the HEIDI cooperative fluid HMI to be developed in the context of this project. This overall goal is aligned with the four HEIDI objectives (#1 - #4), as described below.

- HEIDI Obj. #1: Develop and demonstrate fluid, cooperative HMI solutions.
- HEIDI Obj. #2: Develop technical innovation modules for mutual awareness between road users and drivers.
- HEIDI Obj. #3: Develop suitable validation methods for assessing fluid, cooperative HMI solutions.
- HEIDI Obj. #4: Recommendations for regulation, standardisation, and development of adaptive internal and external HMIs.

The definition of user types and user needs, as targeted in this deliverable, will set the grounds for further work to be developed in WP1, in the framework of deliverable D1.2, where several use cases will be designed, WP2 (internal HMI to interact with the ego-driver), WP3 (external HMI to interact with vulnerable road users and external drivers), and WP4 (fluid cooperative HMI that will synchronize the internal and external HMIs). A detailed taxonomy of user types and user needs must be built with clear connections with the different work packages they are related to.

3. Definition of road user types

This chapter provides the definitions of the different types of road users considered in the HEIDI project in the light of their interactions with automated vehicles with different levels of automation (with special focus on SAE levels from 1-3). Several criteria can be used and/or considered with a view to identifying the road user types, such as:

i. Location of user with respect to the ego-vehicle (internal, external).
ii. Vulnerability of user (driver, VRU).
iii. User abilities and control (regular, elderly, children, reduced mobility, reduced sensing ability, reduced cognitive capacity).
iv. Groups of road users.

3.1 Overview of road user types

3.1.1 Vulnerable Road Users

Vulnerable road users can be pedestrians, cyclists, and other two-wheelers [24]. The HEIDI project will focus on pedestrians, given the potential of HMI systems to provide fluid interactions between pedestrians and vehicles. Pedestrians can differ in:

i. Type (adults or children).
ii. Level of attention.
iii. Potential disabilities (physical or visual).
iv. Number (alone or larger group).

3.1.2 Ego-driver

The ego-driver is the driver of the main vehicle we are focusing on. In the scenarios, the ego-driver will approach a crosswalk and must react accordingly (Figure 3–1).

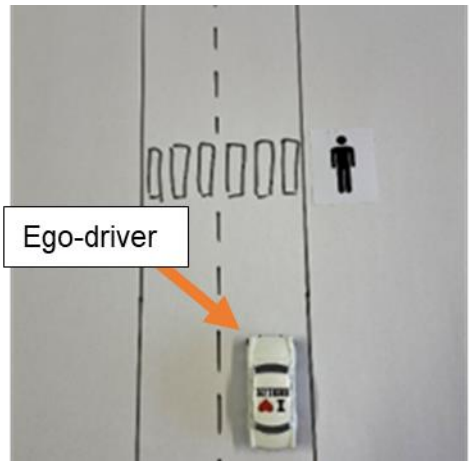

Figure 3–1. Picture that shows the ego-driver in the pedestrian crossing scenario.

There are various characteristics in which ego-drivers differ from each other. In HEIDI we consider characteristics of the drivers in terms of attentiveness and age (regular drivers, distracted drivers, older drivers) and the driver role ascribed to them depending on the level of driving automation (fully responsible, fallback-ready, out-of-the-loop; [1]).

With higher driving automation level, the driver´s tasks reduce and thus the differences between driver types become less relevant. Hence, we do not differentiate driver types for fallback-ready and out-of-the-loop drivers. In consequence, we focus on five different ego-driver types in HEIDI (see **Table *3-1***).

Table 3-1. Overview of five ego-driver types that result from the classification by driving automation level and the characteristics attention level and age.

		Driver type		
		Regular	*Distracted*	*Older*
Driver role based on SAE level	*Fully responsible*	Fully responsible regular driver	Fully responsible distracted driver	Fully responsible older driver
	Fallback-ready	Fallback-ready driver		
	Out-of-the-loop	Out-of-the-loop driver		

3.1.3 External drivers

In HEIDI, external drivers are in the same scenario as ego-drivers and vulnerable road users and interact with them in traffic scenarios. Within the project, no differentiation is made between different types of external drivers. All car drivers that surround the ego-driver in a traffic scenario can be classified as external drivers. We need to distinguish between relevant external drivers and those who are considered to be irrelevant for a specific situation as their presence does not affect the behaviour of the ego-driver nor the communication strategy of the HEIDI system.

3.2 Detailed definition of road user types

3.2.1 Vulnerable Road Users

According to the ITS Directive [24], Vulnerable Road Users (VRU) are defined as "non-motorised road users, such as pedestrians and cyclists as well as motor-cyclists and persons with disabilities or reduced mobility and orientation". Among the different types of VRUs, the HEIDI project focuses on pedestrians, the most frequent type of VRU. The interactions between pedestrians and automated vehicles with different levels of automation (ADAS-assisted) can be significantly enhanced by means of external HMIs (eHMI), as a manner to establish a communication link between them during their interactions on the road environment. However, interactions can be optimized based on the types of pedestrians that can be encountered on the road. The following types can be defined.

i. Older pedestrian: although there is not a fixed definition in the literature, it is common practice to consider as older pedestrians those above 65 years of age.
ii. Children: again, there is not a common definition. The HEIDI project will assume that children are pedestrians under 12 years of age.
iii. Adult pedestrian: pedestrians between 12 and 65 years of age.
iv. Attentive/distracted: this is a subset of the pedestrian road user type, comprising those pedestrians that are not fully attentive to the traffic conditions. These include pedestrians who are handling their smartphones, talking to other pedestrians, or having their gaze direction away from nearby traffic.

v. Disabled pedestrians: this is a subset of the pedestrian road user type, comprising those pedestrians suffering any type of disability (physical or mental), including motor and cognitive (visual/audio) disabilities. Motor disabled pedestrians include, but are not limited to, pedestrians walking on crutches, pedestrians assisted by walkers, and pedestrians on wheelchairs.

vi. Group of pedestrians: it is composed by an undefined number of pedestrians (greater than one) walking together (typically with a distance below 1-2 meters from each other) under similar walking dynamics. A group of pedestrians is supposed to have one or several leaders that have the potential to significantly influence the walking dynamics and behaviours of all pedestrians in the group.

3.2.2 Ego-driver

In the following chapters, we first depict the different roles of a driver depending on the level of driving automation. We then provide an overview of characteristics of distracted drivers and older drivers.

3.2.2.1 Driver roles in different automation levels

The different levels of driver automation change the drivers´ tasks and role. Drivers in SAE level 1 have full responsibility for all driving-related tasks but are assisted in maintaining speed and distance. The responsibilities of drivers using level 2 are the same as in level 0 and 1 but the automation can additionally support in steering. Level 3 drivers are allowed to perform non driving related activities (NDRAs) but need to remain fallback-ready. Fallback readiness includes to take over manual control as the vehicle requires to do so. Starting from Level 4, the ego-driver is not required to remain fallback-ready anymore. The different roles are defined in the second and third row in Figure 3–2. While level 4 is limited to certain conditions (e.g., road areas), level 5 automation can handle all possible conditions.

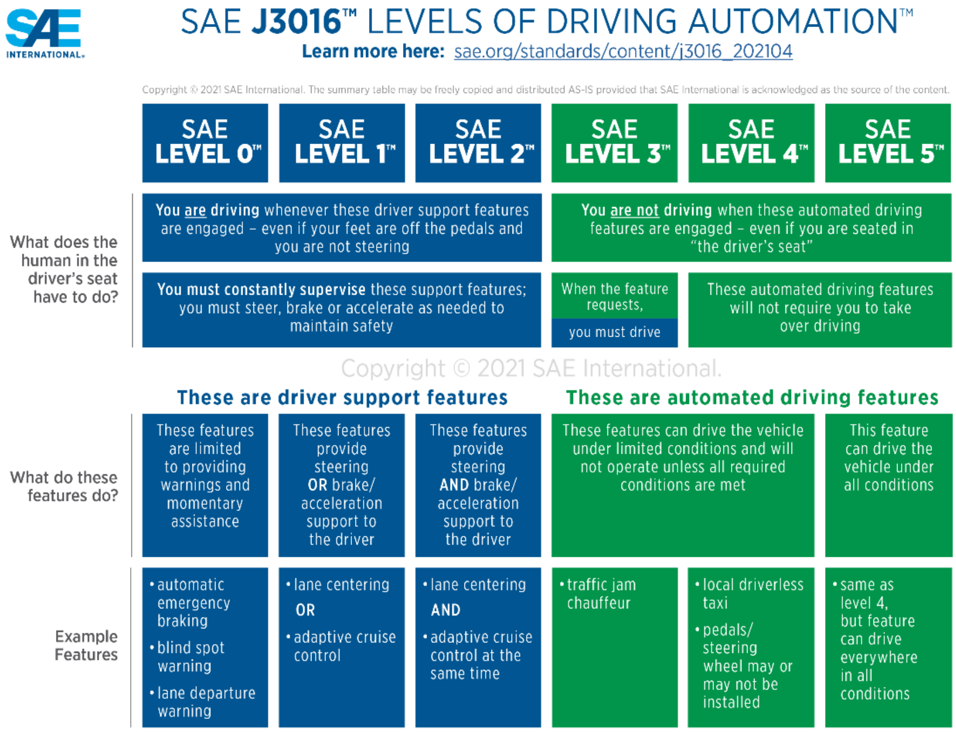

Figure 3–2. SAE levels of driving automation [1].

The differentiation of driving automation into the six SAE levels results from the technological boundaries. However, from a driver´s perspective the levels of automation result in only three types of driver roles. Up to level 2, drivers are fully responsible for driving and are only supported by driving automation. The tasks and responsibilities of the fully responsible driver do not change compared to manual driving. In level 3, driving automation can take over the driving task, however, the driver needs to remain fallback-ready. Starting from level 4, drivers become passive and are not required to be fallback-ready. The described driver roles are summarized in Table 3-2.

Table 3-2. Driver roles in automated driving identified in [1].

SAE level of driving automation	Driver role name	Driver role definition
Level 0, Level 1, Level 2	Fully responsible driver	Driver is fully responsible for all driving activities such as steering, braking or accelerating.
Level 3	Fallback-ready driver	The driver does not have to perform the driving activities but needs to remain fallback-ready. Whenever the driving automation requests it, the driver has to take over all driving activities.
Level 4, Level 5	Out-of-the-loop driver	The driver does not have to perform the driving activities. Fallback-readiness is not required.

Fully responsible drivers (SAE level 1 and 2) must fulfil the same responsibilities as manual drivers but in a more challenging setup. Compared to manual driving the support in lateral and longitudinal control brings the temptation to stay less attentive. The U.S. national highway traffic safety administration investigates some vehicles with SAE level 2 if they "exacerbate human factors or behavioural safety risks by undermining the effectiveness of the driver's supervision" [32]. Thus, fully responsible drivers differ from manual drivers regarding the risk of insufficient supervision.

Fallback-ready drivers benefit from advanced driver assistance systems (ADAS) and are allowed to perform some NDRAs but need to take over control if requested by the vehicle. When performing NDRA, drivers are out of the loop. Being in the loop is defined as being "in physical control of the vehicle and monitoring the driving situation" while being "out of the loop" is defined as being "not in physical control of the vehicle, and not monitoring the driving situation, OR not in physical control of the vehicle but monitoring the driving situation (on the loop)" [52]. HMIs can support drivers to come back into the loop as requested and safely take control [33].

Out-of-the-loop drivers can fully concentrate on NDRAs and have no driving related responsibilities. Consequently, the driver does not need to be considered to evaluate safety critical aspects like monitoring the street.

3.2.2.2 Distracted drivers

Distracted drivers are drivers that have their attention diverted away from activities for safe driving toward another activity [34]. Distraction occurs when a driver 'is delayed in the recognition of information needed to safely accomplish the driving task, because of some event, activity, object, or person within or outside the vehicle compels or induces the driver's shifting attention away from the driving task [35]. Driver distraction can be technology and/or non-technology-based and can be cognitive and/or visual.

Technology-based distraction includes distraction by mobile phones, navigation systems, emails, the internet, or entertainment systems. Non-technology-based distraction can be eating, drinking or smoking [36]. In a naturalistic driving study, distraction by a secondary task was found as the biggest contributing factor to inattentive driving [37].

Visual distraction impacts driving more than cognitive distraction. Cognitive distraction reduces the smoothness of steering. All distractions cause problems in steering. Visually distracted drivers neglect and over-compensate, and cognitively distracted drivers under-compensate. Furthermore, visual distraction and the combination with cognitive distraction negatively influence vehicle control and hazard detection. Furthermore, distraction causes long off-road gazes [38].

Distracted drivers have an increased risk for road fatalities. In a naturalistic driving study, inattentive driving was related to 78% of all accidents and 65% of all near-accidents that were documented throughout the study [37]. Calling on a phone brings the highest risk for crashes or near crashes [39] (for an overview see

Table *3-3*).

Table 3-3. Results from a naturalistic driving study [8] on how performing secondary tasks while driving increases the odds ratio for crashes or near-crashes. The odds ratio shows how a task increases the risk of a crash or near-crash.

Task	Odds Ratio	
	Novice Drivers	Experienced Drivers
Cell phone: Dialling	8.32	2.49
Reaching for object other than a phone	8.00	1.19
Reaching for a phone	7.05	1.37
Looking at roadside object	3.90	0.67

Cell phone: Texting or using internet	3.87	(Not enough data)
Eating	2.99	1.26
Adjusting controls other than those for radio or HVAC (Heating, ventilation, and air conditioning)	2.60	0.64
Adjusting controls for radio or HVAC	2.60	0.64
Drinking non-alcoholic beverage	1.36	0.44

3.2.2.3 Older drivers

We define older drivers as drivers aged 65 years or older. The group of older drivers is increasing. This is caused by demographic change and by the increasing car use of older drivers. While commuting and work trips are reduced after retirement, shopping and leisure trips are continued and only decrease in high ages [40]. On average, older drivers stop using their car when they are being between 72 (UK, [41]) and 75 years old (Sweden, [42]). Age and gender are the best predictors for self-imposed driving limitation. Further predictors are that drivers notice their own inattentiveness, errors, and health impairments [42]. In general, speeding is reduced with advancing age [43].

Older drivers aged 75 years and above have a higher fatality rate than regular drivers. Different medical conditions are the reason for higher risk in older drivers. The national institute on aging describes problems related to stiff joints, stiff muscles, seeing, hearing, reacting time and reflexes and medication [44]. In general, medical conditions increase the number of fatality risks (see **Table *3-4***). In consequence, the higher number of medical conditions in older drivers increases the accident risk in older drivers.

Table 3-4. Increased fatality risk by different medical conditions [45].

Medical Condition	Increased risk by	Number of studies analysed
Neurological diseases	75%	22
Mental disorders	72%	33
Diabetes mellitus	56%	25
Cardiovascular diseases	23%	48
Hearing impairment	19%	5
Arthritis/Locomotor diseases	23%	48
Vision impairment	9%	79

A literature review summarized research on visual conditions in older drivers. Reduced peripheral vision (visual field) and the reduced ability to see details of moving objects (dynamic visual acuity) are problems for older drivers that increase the risk for road accidents. Whether a decreased visual acuity and colour vision results in higher accident rates is a controversial discussion in literature. Literature suggests that a loss of binocular vision does not contribute to road accidents [46].

3.2.3 External drivers

3.2.3.1 External driver types

For external drivers we do not distinguish between different types of drivers with respect to their capacity and age since it is hardly possible to infer information about their mental state or age from the perspective of an ego-driver. In fact, similar to the definition of the ego-driver, external drivers can also appear with different levels of automation as other drivers can also use fully or partially automated vehicles (see Table 3-2).

For external drivers another distinction between different types of vehicles could be made since they might have partially different needs compared to passenger car drivers (e.g., truck drivers need to stay together in a group during platooning on highways without cars cutting in between [25]). Since HEIDI mainly focuses on the interaction between vehicles and VRU such as pedestrians in an urban environment, the particular consideration of external truck drivers exceeds the scope of this project. Thus, truck drivers are being considered in the same manner with the same needs as passenger car drivers.

3.2.4 Summary

Table *3-5* summarizes the different road users considered and their potentially reduced abilities, including distraction, cognitive disabilities due to age or to other reasons, and physical disabilities (visual and motor-wise).

Table 3-5. Summary of road user's types.

		regular	reduced abilities				
			distracted	age (cognitive)		disability (physical)	
				old	young	visual	motor
Ego-driver		x	x	x			
Other drivers		x					
VRU	Pedestrian	x	x	x	x	x	x
	Group of pedestrians	x	x				

4. Road user needs

Once the types of road users to be considered have been properly defined, it is time to identify their respective needs in the context of their interactions with automated vehicles with SAE levels from 1 to 4. The identification and definition of specific user types will enable the construction of relevant use cases in WP2, WP3, and WP4, as indicated in Table 4-1, where the connection between the road user type and the relevant, subsequent work package is indicated in each case.

Table 4-1. Road user's types and their links to work packages in HEIDI.

	User	Numerosity		Automation		Regular	Attention	Cognitive ability	Sensing ability	Mobility
		Single	Multiple	No (SAE-L0)	Partial (SAE-L3)		reduced (distracted)	reduced (elderly)	reduced (visual/aural)	reduced (crouches wheelchair)
WP2	Ego-driver	X	-	X	X	X	X	X		
WP3	Other drivers					X				
WP3	VRU	X	X	-	-	X	X	X	X	X
WP4	all									

Different user needs will be analysed with the goal of providing the grounds for further describing the desired specifications of the holistic HMI to be developed in HEIDI, while considering the level of automation of the ego-vehicle and other vehicles (manual – partial automation). Potential features to include in the description of user needs include but are not limited to enhanced safety, optimised driving efficiency, smooth, intuitive, and non-distractive interaction, unequivocal information (from the automated vehicle to road users), reduced mental load for drivers in the long term, improved perception of comfort, and enhanced feeling of respect in road users, especially in those with some kind of disabilities or reduced capacity.

4.1 Ego-driver's needs

Drivers have various general needs and specific needs that differ based on their type and the level of automation in use. Building upon the literature described in the driver definition (3.2.2), we identified central driver needs in the HEIDI scenarios.

Furthermore, we conducted two workshops to identify the needs of older and regular fully responsible drivers when interacting with pedestrians in different situations. Within the workshops, experts on human factors and automated driving first discussed possible challenges of older fully responsible drivers in different interaction scenarios with pedestrians. The scenarios focused on an ego-driver who needs to interact with pedestrians crossing the street at positions with and without zebra crossings (see Figure 4–1). Depending on the scenario, a varying number of external drivers were part of them. Based on the identified constraints for each scenario, the respective driver needs were derived and discussed in a follow-up workshop.

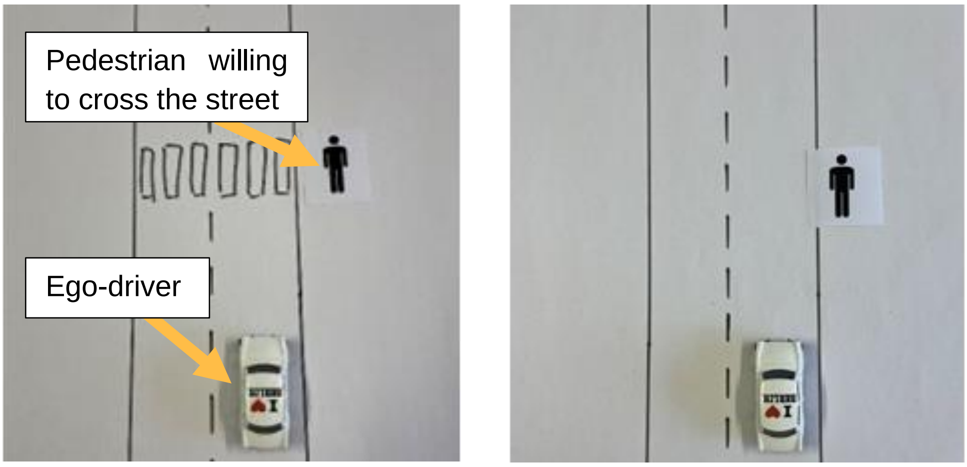

Figure 4–1. Driving situation used to define driver needs. Variations of the scenario include other vehicles and pedestrians.

In the following chapters, we first describe the needs of fully responsible drivers and outline the particular needs of distracted and older drivers (section 4.1.1). An overview of the results of the first workshop, that led to the identification of the different driver needs is provided in section 8 in the annex. Section 4.1.2 provides an overview of the needs of fallback-ready drivers, while the needs of out-of-the-loop drivers are outlined in section 4.1.3.

4.1.1 Fully responsible driver

Fully responsible drivers must focus on the driving task. Their primary need, therefore, is to drive safely without critical situations or accidents. Within this section, we describe regular drivers' needs and then go into detail on how the needs of distracted and older drivers differ.

4.1.1.1 Regular driver

Fully responsible drivers of SAE level 1 and 2 need to calibrate their trust towards the automation capabilities and the driving situation. Calibrated trust allows drivers to adapt their reliance on the automation. Trust calibration needs to be temporal and functional-specific [48]. Malfunctioning assistant systems and automation functions (in Level 1 and 2) can create dangerous situations. However, the driver is fully responsible and thus needs to adequately trust and rely on the automation.

All fully responsible drivers need to make dynamic decisions and perform related actions within the described driving scenarios. [49] defined a model of situation awareness in dynamic decision making. The model describes that the process of building a situation awareness includes the perception of the current situation, understanding the current situation, and predicting future states. Based on this process, a decision on actions needs to be made and executed [49]. In our workshops, we applied the theory to concrete HEIDI scenarios. The resulting driver needs are presented in **Table *4-2***.

Table 4-2. Needs of fully responsible regular ego-drivers when interacting with pedestrians.

Need to:	
1. Interact & Communicate	• To be noticed by other road users • Conflict free interaction • Unambiguous, unconfusing and concise communication • Coherent communication that follows a logical order
2. Allocate attention	• Allocate attention towards driving task • Have a sufficient cognitive spare capacity
3. Perceive	• Perceive road and traffic situation (e.g., zebra crossing, traffic jam) • Perceive pedestrians (properties/features: e.g., position, body size, condition, gaze, salience) • Perceive own vehicle state (e.g., speed, driving mode)
4. Understand	• Understand the situation (Spatial [distance]/causal relationships) • Identify the relevant interaction partner(s) • Understand the intention of individual players
5. Predict	• Predict future situation unfolding • Predict potential danger
6. Execute behaviour	• Refer to proper reaction • Activate and perform consistent behaviour and action plan • Inhibit routine behaviour when not appropriate

With regard to traffic situations where drivers interact with other traffic participants, there is a need for conflict free interaction which can be achieved by cooperation [31]. Therefore, in cooperative traffic scenarios it is indispensable that drivers and other road users are aware of each other and can identify each other as possible interaction partners [26].

In order to successfully solve cooperative situations, traffic participants need to communicate with each other. General communication needs can be derived from [30] and applied to the communication between drivers and other road users. The communication has to be unambiguous and without confusion to achieve a clear understanding of the other's interest and intended behaviour. Moreover, drivers need concise messages since interaction in traffic situations mostly happens within short periods of time. Finally, the signals and messages that are interchanged via different communication channels need to be coherent and follow a logical order. Otherwise, this could lead to misunderstandings that inhibit the successful solution of cooperative traffic situations. The need for interaction and communication is relevant throughout the pedestrian crossing situation (step one to five in **Table *4-3***).

To react correctly in a situation with a crossing pedestrian, drivers need to allocate their attention to relevant aspects. Since regular drivers are generally attentive, we expect them to be able to do so. However, complex situations including several pedestrians and vehicles can make the attention allocation difficult for drivers. Thus, a related need is to have sufficient cognitive spare capacity for allocating attention and the following steps of decision making. As the attention is allocated to the driving situation, drivers need to perceive different aspects of the situation. Most important in our scenarios is perceiving the traffic situation including pedestrians. Drivers need to perceive details of the situation like the condition and gaze of the pedestrians to then understand their intention. Perceiving the own vehicle state (e.g., speed, driving mode) is needed for drivers to have an overview of the entire situation.

Drivers need to understand the situation: they need to understand what the relevant aspects and interaction partners are and focus on them. Perceiving the different aspects of a situation individually cannot provide drivers with a sufficient understanding. Drivers need to combine different aspects of the situation to understand it. For example, combining the information that the vehicle driving in front brakes and that there is a zebra crossing might indicate that a pedestrian walks on the zebra crossing.

To plan an action, drivers need to predict how the situation will unfold in the upcoming moments. For example, drivers need to predict if a pedestrian will start crossing the street or wait in a situation without zebra crossing. If the driver predicts that the pedestrian will wait, the driver can decide to let the pedestrian go or to continue driving. However, if the driver predicts that the pedestrian starts walking, the driver needs to immediately act and brake.

Based on the prediction of the situation, drivers need to plan and execute related behaviour. Remembering possible reactions that were already experienced or learned (e.g., in driving school) can help to make a decision. The driver needs to be consistent in performing the behaviour plan. An execution of inconsistent behaviours like braking and accelerating need to be avoided. However, changes in the situation need to be considered at any time. Inappropriate routine behaviours (e.g., using the cruise control) can conflict with the planned behaviour and needs to be corrected.

4.1.1.2 Distracted driver

Distracted drivers generally have the same needs as regular drivers, but the characteristics of some needs differ (see **Table *4-3***). The main differences result from difficulties in attention allocation and reduced mental capacity due to distraction. Furthermore, switching between tasks costs further cognitive resources [50].

Table 4-3. Needs of fully responsible distracted ego-drivers when interacting with pedestrians.

High-level drivers need	Specific need of fully responsible distracted drivers	Explanation
1. Allocate attention	Recognize where attention is required Understand urgency of events	For distracted drivers it is difficult to notice events that require their full attention A joyful distraction can create an obstacle for being attentive to critical events
2. Perceive	Perceive early enough	Perceiving relevant aspects of the situation in time requires cognitive resources. Due to distraction, distracted drivers have limited resources to fast perceive situational aspects
	Get an overview	Switching between activities reduces cognitive capacities. Limited cognitive resources make it more likely that aspects are overlooked
	Filter relevant information	Limited cognitive resources make it challenging for distracted drivers to filter relevant information

3. Understand	Filter relevant information	The reduced cognitive resources make it difficult to filter relevant information
	Avoid overwhelming/stressful/out-of-control subjective state	A situation with ongoing distraction and critical driving situation will easily overwhelm drivers
4. Predict	Make realistic prediction	Missing cognitive resources can make realistic predictions impossible
5. Execute behaviour	Perform planned behaviour	If the distraction is still ongoing, drivers will have motoric and cognitive problems in performing behaviour

Allocate the attention to important events is difficult when being distracted. However, distracted drivers have the need to somehow notice relevant situations. Further, they need to understand the importance to allocate their attention away from their distraction activity towards the road traffic situation. Attention allocation is especially challenging for driver with distraction that cannot easily be disrupted like a barking dog within the car.

Distracted drivers need to quickly perceive all relevant aspects of critical situations because the following steps could be delayed by distraction. However also getting an overview is slowed due to costs by switching from the distraction task towards perceiving the surroundings.

To save the limited cognitive resources, distracted drivers need to effectively filter the most relevant aspects of the situation. Effective filtering serves the need of not getting overwhelmed when trying to understand the situation.

The distraction makes it difficult to make realistic predictions of how the situation develops. Performing actual behaviour brings motoric challenges for drivers with distraction that includes their hands (e.g., eating, texting).

4.1.1.3 Older driver

Older drivers generally have the same needs as regular drivers, but several aspects of the discussed driving situations are more challenging for older drivers than for regular drivers (see **Table *4-4***). The main differences result from reduced sensory, cognitive, and motor capabilities. Higher experience with driving can benefit older drivers.

Older drivers have different needs for interface design than younger drivers. Younger drivers benefit from a combination of visual, auditory, and haptic feedback on route guidance information. Furthermore, a combination of haptic, auditive and visual feedback results in higher attention of younger drivers. In contrast, a high number of modalities increased the workload of elder drivers. Consequently, older drivers need a personalized interface with intensive auditory feedback and without additional sensory feedback [51] .

Table 4-4. Needs of fully responsible older ego-drivers when interacting with pedestrians.

High-level drivers need	Specific need of fully responsible older drivers	Explanation
1. Allocate attention	Recognize where attention is required	For older drivers is more challenging to allocate the attention to events due to limited peripheral vision
2. Perceive	Perceive early enough	Older drivers need to perceive everything earlier because the following processes take longer for them
	Filter relevant information	Filtering relevant information is more difficult for older drivers but is a more important need for them because the following processes are already slower
	Enhance peripheral vision	Older drivers with limited peripheral vision somehow need to perceive what happens in the periphery
3. Understand	Filter relevant information	Filtering relevant information is difficult for older drivers but is a more important need for them because the following processes are already slower
	Avoid overwhelming/stressful/out-of-control subjective state	Older drivers can get faster overwhelmed
4. Predict	Build upon previous experiences	Older drivers have more experience and likely experienced similar situations already before. It is important that only well-fitting pre-experiences are used as reference for new situations
5. Execute behaviour	Perform planned behaviour	An overwhelming situation could result in unplanned actions. Motoric problems can slow down the execution of planned behaviour

The attention allocation can be difficult for older drivers with visual impairments [46]. Especially events and objects in the peripheral area can be easily missed but older drivers have the need to perceive events happening there.

As the attention is allocated, older drivers need to quickly get an overview of the situation. The following processes of understanding and predicting are slower for older drivers. Thus, the perception needs to happen in time to ensure a timely reaction. Older drivers need to filter the most relevant aspects of the situation to visually focus on these. By focusing on the most relevant objects, older drivers with potential limited vision can perceive all important details (e.g., if the pedestrian is a child or an adult).

In understanding the perceived information, older drivers need to filter relevant aspects to avoid overwhelming situations. This aspect is of high importance because older drivers can get faster overwhelmed.

Older drivers have a high number of previous experiences that can support them in predicting how the situation develops. To use previous experiences safely, older drivers need to select only well-fitting pre-experiences as reference. Applying the experiences from situations that do not fully fit the current situation results in false predictions and thus critical situations.

Performing planned behaviour can be challenging for older drivers due to motoric problems. Thus, older drivers have a high need to quickly and precisely perform the actions they want to perform.

Similarly, in [21], the needs of older drivers are analysed in detail by identifying the corresponding areas of difficulty. Regarding older drivers, taking into account their remaining capacities, as well as the perceived complexity of the driving situations, the following needs have been defined based on [12] [16 - 20]:

1. Regarding intersections (road crossings, T junctions, roundabouts) drivers who are elderly require:
    a. Controlled intersections (traffic lights).
    b. Adequate roadside information.
    c. Roadway design easing the task.
2. Regarding driving onto-off motorways, drivers who are elderly require:
    a. In due time information with adequate size.
    b. A road design allowing to increase the distance to get onto the traffic lane.
    c. Separated slip roads to drive onto/off the motorway in order to avoid conflicting traffic situations.
3. Regarding road works, drivers who are elderly require in due time and clear roadside information.
4. Railway crossings should be avoided and replaced by flyovers; once they impose increased stress to drivers who are elderly that can lead to incidental or accidental situations; at the existing railway crossings, clear and in due time warnings are required.
5. When following a car, taking over, entering and leaving traffic, lane changing, as well as driving on flyovers, bridges and tunnels, drivers who are elderly require:
    a. Good visibility.
    b. Clear information (road sign, one/two flows signs and pavement markings).

Needs #1, #2, #3, and #5 can be clearly connected with automated cars providing adequate and clear information to other drivers by means of external HMIs. Such information has the potential to partially compensate for the needs of older drivers in certain situations. In addition, the use of internal HMIs is an excellent opportunity to support older drivers, so that they can continue to drive without restrictions.

Considering the changes in the driving task related to the use of these new technological systems and its increased complexity, older drivers should be supported by means of internal HMIs that ease the driving task by considering the following aspects:

1. Regarding the strategic level, (navigation) the HMI system should allow for:
    a. A more rapid and effective understanding of the displayed messages.
    b. The development of the senses of direction and distance.
    c. The development of a spatial knowledge representation (cognitive maps), including the representation of routes and their characteristics.
2. Regarding the tactical level (rule-based), the HMI should focus on the interaction with the other road users, using the displayed messages to anticipate their behaviour.
3. Regarding the operational level (skill-based), the HMI must support older drivers in a tutoring manner until they integrate the learning of the system.

Some of the older drivers' needs are connected to improvements in the infrastructure, but there are other needs that can be addressed by means of onboard technological systems and, more specifically, by means of HMIs that ease the interactions with other road users. **Table *4-5*** provides a summary of such needs in the context of assistive interactions with other road users.

Table 4-5. Older Drivers' needs.

Summary of older drivers' needs
When following a car, taking over, entering and leaving traffic onto-off motorways, lane changing, as well as driving on flyovers, bridges and tunnels, drivers who are elderly require clear information about the road structure and the behaviour of other drivers.
Messages conveyed by in-car systems to older drivers must allow them to develop the senses of direction and distance as well as a representation of spatial knowledge about the routes and their characteristics.
Clear information for better understanding intersections (road crossings, T junctions, roundabouts).
In due-time and clear information regarding the presence of road works and railway crossings.
Older drivers need to be alerted in case of drowsiness or decrease of attention.
Older drivers need to receive emergency aids by their in-car systems.
Older drivers need to be assisted by HMI systems that focus on the interaction with the other road users, using the displayed messages to anticipate their behaviour.
Older drivers need to be supported by HMI systems in a tutoring manner until they integrate sufficient knowledge to learn to operate the systems with confidence and without lack of attention.
Appropriate technological systems that maximize and ease the understandability of messages conveyed to older drivers (based on Head-up displays and audible signals, among others) so that they can reduce their mental load and improve their perception of comfort when driving.

4.1.2 Fallback-ready driver

Fallback-ready drivers are drivers that use SAE level 3 automation. Even though fallback-ready drivers are not engaged in driving tasks, based on previous classifications by Merat [52] and Seppelt [53] it is possible to describe a series of potential issues that may occur when facing situations that include interactions with VRUs. These issues include (list adapted from [52]):

- Inability to anticipate situations that lie beyond the capabilities of the automation [54].
- Failure to sample safety-critical areas such as crosswalks at intersections or glances to mirrors, indication with turn signals, and over-the-shoulder glances prior to lane changes [55].
- Increased uptake of secondary and non-driving related tasks [56].
- Unnoticed mode transitions, for example from one level of automation to another [57].
- Low or loss of situation awareness of the state and processes of the system [58].
- Lower self-reported scores in confidence to make decisions (or control vehicle manually) after system failure [59].
- Over trust of the system, and lack of monitoring behaviour, based on an unjustified assumption of satisfactory system state.
- Inaccurate mental models (as measured subjectively by testing knowledge of actions and limits of the system, i.e., its boundary conditions) [60].

To describe in detail the needs of fallback-ready drivers in HEIDI pedestrian crossing scenarios, we divide the driving with SAE level 3 automation into three sequential phases:

- Phase 1: SAE level 3 is active, and the fallback ready driver is allowed to perform NDRAs.
- Phase 2: As the automation triggers a takeover request, fallback-ready drivers have to take back control.
- Phase 3: The automation is deactivated, and the driver drives manually again. The driver is responsible to handle upcoming events.

Since the HEIDI project focuses on driver´s interaction with other road users and pedestrians – which is not required in phase one and two – we focus on describing the drivers' specific needs in phase three. While the drivers' responsibilities are similar to those of a fully responsible driver, we expect a difference in needs that results from being out of the loop for a long time. The general needs of drivers in a pedestrian-crossing scenario are described in 4.1.1.1 and the specific needs of fallback-ready drivers (Phase 3) are described in **Table *4-6***.

Table 4-6. Specific needs of fallback-ready drivers in a pedestrian crossing situation (after taking control).

High-level drivers need	Specific need of fallback-ready drivers	Explanation
1. Allocate attention	Avoid carry over effects (= continued performance of NDRAs)	Drivers that drove level 3 automated vehicles could not understand that they have to end to perform a NDRA or understand it but want to continue their NDRA activity
	Recognize where attention is required	Drivers that only recently took over control could have an insufficient overview and therefore problems in recognizing relevant aspects of the situation
2. Perceive	Perceive early enough	Drivers that drove level 3 automated vehicles need to perceive everything earlier because the following processes could take longer for them
	Get a good overview of the situation	Fallback-ready drivers cannot use information from previous driving situations (e.g., how the vehicle in front behaves) because they drove in level 3 automation
3. Understand	Understand behaviour of other drivers	The lack of knowledge on how the other drivers behaved in previous driving situation makes it more difficult to predict and understand their behaviour
	Avoid overwhelming/stressful/out-of-control subjective state	Problems in getting an overview and understanding the situation leads to stress
4. Predict	Forecast situation based on previous events	Missing information on previous states of pedestrians, due to drivers' disengagement in level 3, makes it difficult to predict intentions and future actions
5. Execute behaviour	Stable vehicle control	After inactivity time (driving in level 3 automation) it may take longer to stabilize the vehicle control

Drivers that recently took control from level 3 automation need to end all NDRAs. The carryover effect describes the continued use of NDRA regardless of the change in the driver's role and responsibilities. Drivers that continue the NDRA will have problems in handling the pedestrian crossing situation.

Drivers that drive manually after a long period of level 3 automated driving have an increased need to fast perceive an overview of the situation. Drivers that drove manually all the time are already aware of the vehicles driving around them and experienced how they drove in previous situations. Since drivers that only recently switched to manual driving don´t have this previous knowledge, they have an increased need for perceiving and understanding the other vehicles' driving behaviour. The unfamiliarity with the driving situation further leads to an increased need to understand the behaviour of the other drivers. Consequently, the risk of being stressed out or out of control is increased. For the same reason, these drivers have a larger challenge in forecasting the situation.

Drivers that recently took control from level 3 automation have an increased need for stable vehicle control. After being not in active control for some time, it can be challenging to control the vehicle in a stable way.

4.1.3 Out-of-the-loop driver

Out-of-the-loop drivers (OOTL) do not need to take care of the driving task anymore. Consequently, their needs are not related to managing the driving situation and interaction with pedestrians but to aspects like comfort and NDRAs. We do not differentiate between regular, older, and distracted drivers because we do not expect critical differences in comfort and/or NDRAs needs when being out of the loop.

Drivers have a need for physical (sensory) and cognitive comfort of driving and non-driving tasks. Furthermore, drivers need to accept the driving automaton. Thus, the vehicles driving behaviour should be foreseeable and human-like. Drivers further have the need for connectivity in the vehicle by multi-sensory natural interaction (e.g., gaze, gesture, speech) [47].

OOTL drivers need to understand the vehicle behaviour, such that it feels natural and consistent with the surrounding road and traffic conditions, as well as ensuring comfort at all time and adaptation to varying external conditions and driver’s NDRAs.

The driving style of the vehicle must support the current activity of the driver, i.e., the driver needs to not be disturbed or interrupted by vehicle reactions. In other words, the current condition and activity of the driver needs to be maintained and preserved by the physical behaviour of the vehicle.

This ability of the vehicle to adapt to the conditions of the driver (and passengers) implies the ability of the system to monitor, interpret and update the knowledge about the driver state, activity, preferences and expectations, i.e., psychophysical state.

On the other side, drivers must be informed of activities that are, or are not, allowed in specific situations, which may vary even in autonomous driving mode (e.g., sleeping may not be allowed if a take-over is planned within minutes, and the driver’s posture, i.e., seating position, should gradually be adjusted to facilitate the take-over).

This can be seen as a need of the driver to be gradually brought into the proper psychophysical conditions for taking over the driving tasks. Therefore, drivers still need to be provided with clear and concise information about the vehicle state, behaviour and intentions, including planned changes and updates thereof. Drivers in automated vehicles may still need to participate in high-level navigation tasks, i.e., route selection, upon encountering conditions that were not originally planned (e.g., traffic jam), with no need to be involved in vehicle control. This would guarantee a smooth and uninterrupted positive experience during the whole travel and minimize interactions with VRUs.

The privacy and private data of people in the vehicle must be protected. This is a need that is emerging more and more with increasing automation system and the increasing knowledge that those systems need to acquire about drivers and surrounding environment. V2X communication, i.e., connected automated vehicles (CAVs), need indeed to share a large amount of data to develop prediction abilities with regards to traffic and navigation tasks. Drivers, therefore, are constantly monitored and data are broadcasted and exchanged to increase the efficiency of the computations. Finally, an important need for all users of autonomous vehicles is to be aware (and possibly assured) of the abilities and performance that the vehicles can achieve along the route. This would encompass information about the vehicle driving style and human-like abilities, i.e., the similarity of the perception and action tasks the AI-based system is trained for and able to cope with.

4.2 Vulnerable road users' needs

Vulnerable road users include pedestrians, cyclists, and other two-wheelers. However, as already mentioned in the previous section, HEIDI will mostly concentrate on pedestrians, which are the most unprotected road users and, in most countries, represent an unwarranted percentage of traffic fatalities. As described in [2], the increasing motor traffic in cities negatively affects the safety and environment of pedestrians. Pedestrians make up 15-20% of the deaths in road accidents in industrialized countries; this is 40-50% in developing countries [3]. Other problems related to comfort and security also have to be considered in order to obtain a more pedestrian-friendly environment that promotes walking as a means of transport. Consequently, multidisciplinary research is needed to refine and increase knowledge of the behaviour of pedestrians, and to promote walking as a valuable way to enjoy city life and maintain health. If developments on automated driving and transportation planning included these considerations, all projects would be required to include safe, connecting pedestrian provisions. Unfortunately, this is not the case on most occasions. Thus, understanding and providing for the needs of pedestrians is paramount to automated vehicles, intelligent transportation systems, and urban design projects.

In [4] an analysis of pedestrian safety features is carried out by identifying a number of safety tips describing some basic pedestrians' needs from the perspective of the drivers, i.e., the desired behaviour for drivers in order to account for and respect pedestrians needs. These tips (8 safety tips for drivers) give very clear indications on how the drivers (or automated cars) behaviour should be shaped in order to respect these pedestrian needs. In other words, these safety tips can be directly translated into pedestrians needs when interacting with vehicles with different levels of automation, from manually driven to partially or fully automated. **Table *4-7*** provides the list of safety tips for drivers (left column) with their corresponding, desired behavioural features in automated vehicles (right column). These behavioural features can be directly identified as pedestrians' needs when interacting with vehicles.

Table 4-7: Safety tips for drivers vs. pedestrians' needs when interacting with automated vehicles.

Safety Tips for Drivers (when interacting with pedestrians)	Pedestrians' needs when interacting with automated vehicles
Look out for pedestrians everywhere, at all times.	Pedestrians must be robustly perceived by automated vehicles at all times.
Use extra caution when driving in hard-to-see conditions, such as night-time or bad weather.	Pedestrians must be correctly perceived by automated vehicles, even under adverse weather conditions and at night-time, taking into account that pedestrians act in the same hard-to-see conditions.
Slow down and be prepared to stop when turning or otherwise entering a crosswalk.	Automated vehicles must slow down when approaching crosswalks and provide fast and

	safe braking in emergency situations when encountering pedestrians.
Yield to pedestrians in crosswalks and stop well back from the crosswalk to give other vehicles an opportunity to see the crossing pedestrians so they can stop too.	Automated vehicles must slow down and stop early enough when approaching crosswalks, yield to pedestrians, and provide signals, when possible, to other drivers.
Never pass vehicles stopped at a crosswalk. There may be people crossing where you can't see.	Automated vehicles must not pass other vehicles at a crosswalk and remain vigilant for the presence of emerging pedestrians.
Never drive under the influence of alcohol and/or drugs.	Fully automated vehicles never suffer from this problem that affect human drivers. However, in partially automated vehicles, the safety system must guarantee a safety stop whenever it detects that the driver is under the influence of alcohol and/or drugs. In any case, guaranteeing that the driver of an ADAS vehicle is not under the influence of alcohol or other drugs remains the drivers' responsibility.
Follow the speed limit, especially around people on the street, in school zones and in neighbourhoods where children are present.	Automated vehicles must respect the speed limit, especially around pedestrians and special areas.
Be extra cautious when backing up and look for pedestrians.	Pedestrians must be robustly perceived by automated vehicles in all directions. Backing-up manoeuvres need to be handled differently depending on whether the car is AD or ADAS, because for an AD vehicle the perception capabilities should be the same both for driving forward and backward, which is not the case for a human driver.

According to COST-358 [5] about Pedestrian Quality Needs, there are four basic needs of pedestrians: "the need for basic mobility", "the need for safe mobility", "the need for convivial mobility" and "Challenging Sojourn". Pedestrian needs can be looked upon in different ways. COST 358 on Pedestrian Quality Needs identifies "functional" and "perceived" needs of pedestrians. Functional needs are the pedestrians' physical needs. One way to identify functional needs is through observation and surveys. Pedestrian behaviour reveals their functional needs. Obviously, functional needs differentiate among different pedestrian groups. Figure *4–2* shows a Maslow-like hierarchy of functional needs, which are divided into 3 levels: preconditions, dissatisfiers and satisfiers. On the other hand, perceived needs are the pedestrian needs which are related with the emotional point of view. They are determined by studying the perceptions of pedestrians or potential pedestrians. People's perceptions are affected by many factors such as the social norms, education, the environment, experiences etc. As society changes many of these factors change and consequently perceptions about pedestrian needs change too. One major issue when examining perceived needs of pedestrians is the following question: "what are the required facilities and provisions for the pedestrians in order to perform pedestrian tasks adequately?" [6]. According to Townsend [7] the factors which make walking environment adequate for pedestrians are smooth footpaths, wide footpaths, adequate connection streets, safe crossings, good shortcuts, seating, adequate lighting, few cars, low speeds, clean air, footpaths with trees, and friendly buildings. Among these, there are three that can be provided by means of automated vehicles with advanced HMI systems, namely safe crossings, few cars, and low speeds.

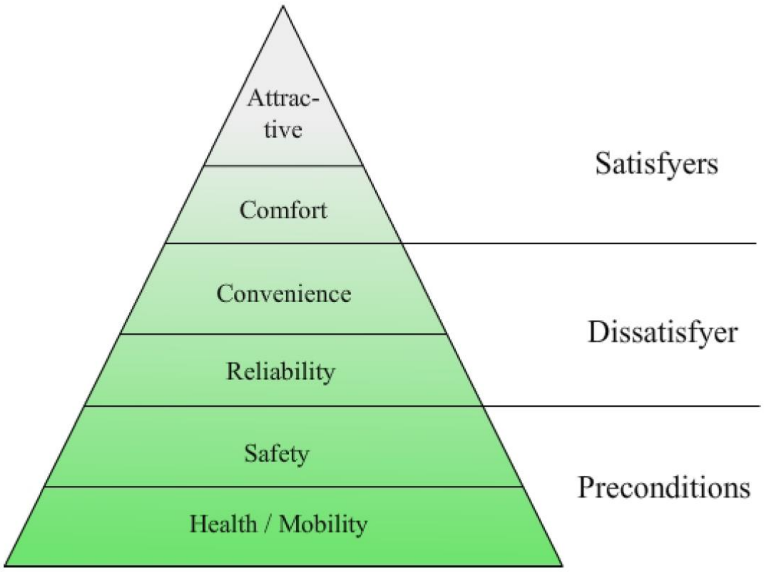

Figure 4–2: Maslow-like hierarchy of pedestrian functional needs: source [5].

In [8], it is clearly stated that the feeling of safety during walking is one of the most important factors which play a crucial role during people's decision for walking. According to the results from an American telephone survey, which was carried out in October 2002 by Belden Russonello and Stewart [9], (national random sample of 800 adults, age 18 and older from October 23 to 30, 2002) Americans would like to walk more but speeding and inadequate infrastructure, such as dangerous intersections, discouraged them.

In [10], it is affirmed that a pedestrian-centred needs-assessment of the walking environment would elicit a more authentic representation of the attributes that contribute to the walkability of the pedestrian environment. This representation can only be developed based on an individual's actual experience of such environment, yielding a categorization of six pedestrian needs criteria, namely: mobility, protection, ease, equitable access, enjoyment and identity, as defined in **Table *4-8*** [11].

Table 4-8: Categorization of pedestrians' needs: source [11].

Needs	Description
Mobility	Barrier-free movement from point of origin to destination.
Protection	Safe and secure walking experience.
Ease	Emotionally and mentally secure, comfortable, convenient and stress-free walking experience.
Equity or equitable access	Equitable access to everyone (e. g. transport-disadvantaged persons), allows various activities and opportunities to take place.
Enjoyment/leisure	Opportunities for self-expression, socialization, and interaction.
Identity	Sense of place, sense of belonging, unique and distinctive character of place, which includes the ideology and culture of the place.

The authors of [10] conducted a survey based on these criteria. Amongst the six criteria, survey participants responded that the provision of a safe and secure walking environment is an important motivation to walk, which is a key attribute that contributes toward pedestrian need for protection. In this case, it clearly revealed that protection, garnering a weighted score or a global priority of 0.232, is the most important criterion while, on the other hand, enjoyment (priority: 0.113) is the least important. Protection is followed by ease (priority: 0.178), which refers to the quality of the sidewalk environment that would make one feel emotionally and mentally secure, comfortable, convenient and stress-free while walking; this is then followed closely by equitable access (priority: 0.175). Equitable access encompasses elements which improve the quality of access within the sidewalk environment for all types of individuals to use as well as equal opportunity to accommodate diverse activities within the pedestrian environment (Mitchell and Burton, 2006; Jacobs, 1961). Equitable access, therefore, refers to the ability of sidewalks not only to accommodate different users but also different uses. Mobility is considered as the fourth most important criteria (priority: 0.153) while identity (priority: 0.150) is fifth and, last in the list of criteria is enjoyment (priority: 0.113). It is interesting to note that mobility, the traditional basis for the design of sidewalks, comes only fourth in the hierarchy. This result has important implications to both theory and practice in pedestrian space design and planning, mostly focused on mobility, as well as in the development of automated vehicles that interact with pedestrians.

Apart from the factors identified in the state of the art, there are pedestrian needs specifically related to the interactions between pedestrians and automated vehicles. In our own analysis, the following needs have been identified:

- ✓ Enhanced safety: interactions with automated vehicles must lead to larger time gaps with respect to pedestrians, as empirically demonstrated in the BRAVE project [23], and a smaller number of dangerous behaviours (such as risky crossings, etc.).
- ✓ Smooth, intuitive, and non-distractive interactions with automated vehicles at crosswalks. This includes receiving unequivocal information from the vehicles' HMIs.
- ✓ Improved perception of comfort and enhanced feeling of respect when interacting with vehicles at crosswalks.

As a wrap-up, **Table *4-9*** provides a summary of the main pedestrians' needs, where the priority has been put on those that aim at the interactions with automated vehicles.

Table 4-9: Summary of pedestrian's needs in their interactions with automated vehicles.

Pedestrian's needs in their interactions with automated vehicles
Pedestrians must be robustly perceived by automated vehicles at all times and in all directions, including under adverse weather conditions and at night-time.
Pedestrians need to be respected by automated vehicles at crosswalks by means of early stops and by the use of appropriate and unequivocal vehicle signalling (as a means to acknowledge the presence of the pedestrian).
Walking ease: Emotionally and mentally secure, comfortable, convenient and stress-free walking experience.
Enhanced safety: interactions with automated vehicles must lead to larger time gaps with respect to pedestrians and a smaller number of dangerous behaviours.
Smooth, intuitive, and non-distractive interactions with automated vehicles at crosswalks.
Improved perception of comfort and enhanced feeling of respect when interacting with vehicles at crosswalks.

4.2.1 Older pedestrians' needs

Among pedestrians, the most vulnerable ones are children, elderly, and disabled pedestrians, given that they usually require more room on sidewalks, more time to cross streets, better visibility at crossing areas, and smoother surfaces than other pedestrians. An analysis of the literature reveals that elderly and disabled pedestrians are usually included in the same group [12], since they suffer quite similar limitations when facing the difficulties of walking in regular traffic. As a matter of fact, elderly pedestrians (and children) can be considered as pedestrians with reduced abilities or capacity. This section analyses their needs, with a specific focus on their interactions with automated vehicles. A very interesting analysis of elderly perceptions of critical issues of pedestrian paths is carried out in [16]. The aim of such study is to understand the most critical issues that elderly pedestrians face when walking and, more importantly, to analyse the key elements that influence their perception and how such perceptions vary based on human factors. Age-related declines in perceptual, cognitive, and physical abilities have been proved to derive in non-optimal street-crossing decisions and behaviours [17][18][19] and contribute to the high accident rate involving elderly pedestrians [20]. On the grounds of these perceptual, cognitive, and motor limitations, elderly pedestrians are expected to experience more difficulties than young and/or middle-aged pedestrians. Some of difficulties identified in the experimental study conducted in [16] include the presence of zebra crossings with supplemented with traffic lights and adequate street lighting. As a matter of fact, participants in the study reported to deviate from their shortest route in order to use a zebra crossing. Especially relevant were the concerns expressed related to the behaviours of other road users. In particular, participants disliked streets with speeding cars and street crossings where approaching cars were not visible. They also mention their appreciation for drivers being courteous and giving priority to pedestrians at crossings. After review and quality check, the final sample of the study was composed by 306 participants (156 men and 150 women). The majority of respondents (50.33%) were aged between 70 and 75. 28.10% of respondents were aged between 75 and 80 and 21.57% of respondents were over 80. Participants were questioned in person, instead of being left alone with the questionnaire, in order to provide explanations and clarifications. Participants in this study identified a total of 16 critical issues, as illustrated in **Table *4-10***.

Table 4-10. Critical issues perceived by older pedestrians.

Critical issues of pedestrian paths as perceived by older pedestrians	
1	Sidewalks too narrow.
2	Absence of sidewalks.
3	Uneven sidewalks.
4	Presence of obstacles on sidewalks.
5	Absence of pedestrian crossing.
6	Faded pedestrian crossing.
7	Incorrect positioning of pedestrian crossing.
8	Absence of assistance ramps on sidewalks.
9	Vehicles parked on the sidewalks.
10	Parked vehicles that obstruct pedestrian crossings.
11	Inadequate drivers' behaviour.
12	Damaged road pavement.
13	Roadway too narrow and absence of sidewalks.
14	Absence or inadequacy of street lighting.
15	Absence or inadequacy of signalized pedestrian crossings.
16	Other.

Participants in the study suffer vision problems (47.06%), hearing problems (67.97%), and mobility problems (75.82%). A more detailed analysis reveals that hearing and mobility problems clearly condition the perception of urban pedestrian paths, although it seems that the elderly are mainly conditioned by vision (or visibility) problems, i.e., the difficulty of correctly seeing the paths themselves and of perceiving the information deriving from the road environment as a whole. As a consequence, the need for having street crossings well illuminated where approaching cars can be fully visible, has been identified as a primary necessity for the elderly. The study also highlights the fact that the speed of elderly pedestrians does not itself increase the accident risk: the risk comes from the speed of the traffic and, in particular, from automated signals (traffic lights) that do not allow sufficient time for slower pedestrians to cross safely. Among the critical issues highlighted in **Table *4-10***, issues #6 (faded pedestrian crossings), #7 (incorrect position of pedestrian crossings), #11 (inadequate drivers' behaviour), and #15 (absence or inadequacy of signalized pedestrian crossings) are considered as factors that can be mitigated to some extent when interacting with HMI-equipped automated vehicles, as those targeted by the HEIDI project. In fact, the recommendations point toward the following actions: improve the interactions between older pedestrians and other road users; increase the perception of pedestrians by other road users; increase the time allocated for pedestrian crossings when they suffer some kind of disability of reduced capacity. Similar conclusions are drawn in [12], where, in addition, two major recommendations are made: to provide audio signal to tell visually impaired pedestrians when the lights are green for crossing; to use people detectors to extend the pedestrian phase for slow walkers. These conclusions and recommendations are totally in line with what HMI-equipped automated vehicles can do to improve the quality and safety of interactions with older and/or disable pedestrians at signalized and unsignalized crossings.

In [21], the needs of older pedestrians have been defined as a consequence of the age-related sensory, cognitive and motor decreasing abilities, as well as their vulnerability. The identified needs are provided below:

1. Regarding street crossings, pedestrians who are elderly require:
    a. Protected street crossings.
    b. Enough crossing time allocated to cross safely.
2. Regarding pedestrian areas, pedestrians who are elderly require:
    a. Regular pavements.
    b. Reduced difference in levels (sidewalks).
    c. Absence of barriers.
    d. Ramps provided of handrails, particularly in curves.
    e. Lifts instead of stairs.
    f. Adequate length and height of steps.
3. Pedestrians who are elderly require good accessibility and safety at underground car parks and silos.
4. Regarding the use of public transport, people who are elderly require:
    a. Reduced gaps in bus/trams stops and metro/railway stations.
    b. Lifts instead of stairs and escalators.
    c. Adequate length and height of steps when existing.

d. Reduced walking distances.

e. Adequate speed and design of escalators and string beans.

These needs are very much in line with those reported by other similar studies in the state of the art, as already described in this section. Among those, need #1 (regarding street crossing) can be strongly assisted when interacting with automated vehicles equipped with intelligent sensing and external HMIs. As a wrap-up of all the needs highlighted in this section, **Table *4-11*** provides a summary of older pedestrians' needs with a special focus on those related to the interaction with vehicles.

Table 4-11. Older Pedestrians' needs.

Summary of elderly pedestrians' needs
Regarding street crossings, pedestrians who are elderly require protected street crossings with enough crossing time allocated to cross safely.
Older pedestrians need clearly visible crossing areas, properly positioned, and properly signalized.
Older pedestrians need to be seen and perceived by drivers well in advance.
Drivers' behaviour must be appropriate when interacting with older pedestrians on crossing areas in order to increase their feeling of being respected by drivers and to improve their perception of comfort.
Older pedestrians need to receive clear, unequivocal, and non-distractive information from drivers when interacting with vehicles at crossing areas.

4.2.2 Groups of pedestrians

A group of pedestrians can be understood as a group composed of several pedestrians (more than one) that walk under the same dynamics. In this regard, their needs are very much in line with the needs already described in previous sections for pedestrians. As a main difference, a leader must be identified in a group of pedestrians, under the assumption that all other pedestrians in the group will follow the behaviour of the leader. Once the leader of the group has been identified, the needs of pedestrians, as already described in previous sections, will be applied to the identified leader of the group of pedestrians. This assumption will have to be validated in practice.

4.3 External drivers' needs

In the literature, there is no distinction between driver needs from an ego perspective and an external perspective. Most research takes the general needs of drivers into account or focuses on the communication needs during interaction between (partially) automated vehicles and human drivers [26, 27, 28, 29]. This can be argued by the fact that switching the perspective on a driver (whether a driver is considered as an ego-driver or an external driver) does not change the fundamental needs. Thus, the basic needs of a regular driver also apply to external drivers with respect to their level of automation (see section 4.1.1.1). In fact, there is a deviation between the weighting and the prioritisation of the ego-drivers' needs and the needs of external drivers depending on the personal preferences of the drivers themselves and the traffic situations.

In the context of HEIDI, special needs of external drivers can be derived in terms of communication and interaction with AD/ADAS vehicles. Moreover, the needs of external drivers can be addressed in a different manner and to a different extent depending on the functionality of the eHMI. The following aspects outline necessary information that need to be provided to external drivers.

4.3.1 Necessary information provided to external drivers

- Driving/operating mode of the vehicle (whether in AD/ADAS mode or not) [26, 28, 29].
- Information about the perception of the environment, or the detection of possible interaction partners respectively [26].
- Information about the intended behaviour and the next manoeuvres [26, 28, 29].
- Cooperation capabilities, i.e., information about the "willingness" of the vehicle to cooperate and advice what to do or what not to do [26, 28, 29].

5. Conclusion

This document provides a description of road users' needs in the context of the HEIDI project. The different types of road users have been defined in detail and their corresponding user needs have been analysed. As a conclusion, the following main types of road users have been considered:

- Ego-driver (driver of a partially automated vehicle equipped with an iHMI). This category includes regular drivers, distracted drivers, older drivers, drivers with disabilities, fall-back drivers, and out-of-the-loop drivers.
- External drivers (drivers interacting with automated vehicles equipped with an eHMI).
- Pedestrians: this category includes adults, older pedestrians, children, pedestrians with disabilities, distracted pedestrians, and groups of pedestrians.

The main user needs have been summarized for each user type and subtype, with a special emphasis on those needs that are related to interactions with automated vehicles equipped with external and/or internal HMIs. These user needs provide the grounds for the definition of use cases (to be described in deliverable D1.2) that will be tested and assessed in the context of WP2 (iHMI), WP3 (eHMI), and WP4 (fluid HMI). As a preliminary risk, some of the assumptions considered in the definitions of user types will have to be validated in practice, such as the predominant dynamics (or leaders) in the groups of pedestrians.

6. Abbreviations

Term	Definition
CAV	Connected and Automated Vehicle
DEC	Websites, Patent Filings, Videos, etc.
DEM	Demonstrator, Pilot, Prototype
eHMI	External Human-Machine Interface
HEIDI	Holistic and adaptivE Interface Design for human-technology Interactions
HMI	Human-Machine Interface
NDRA	Non driving related activity
iHMI	Internal Human-Machine Interface
OOTL	Out-Of-The-Loop
PU	Public
R	Document, Report
SAE	Society of Automotive Engineers
SEN	Sensitive
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-X communication system
VRU	Vulnerable Road Users
WP	Work Package

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8. Annex – Workshop results on challenges for older drivers when interacting with pedestrians

This section provides an overview of the results of the first workshop on identifying older ego-driver needs when interacting with pedestrians who are about to cross the street at a zebra crossing (situation 1-7) or without zebra crossing (situation 8-9).

Situation 1: Pedestrian waiting at right side of zebra crossing

Figure 8–1:Situation 1: Pedestrian waiting at right side of zebra crossing

Visibility of pedestrian may be clear (left) or limited, e.g., due to parked cars (right)

Challenges for an older driver:

- Perceiving the pedestrian at all (due to limits in peripheral vision) / in time / early enough.
- Problem to miss a pedestrian first but notice them suddenly late.
- The driver may get confused and startled and could press the gas pedal instead of the brake.
- Perceiving of the zebra crossing (e.g., markings may be already faded) at all / in time – it may be missed completely.
- Understanding if the pedestrian wants to cross or not, i.e., the intention of the pedestrian (e.g., is s/he only standing there typing on a smart phone or really wants to cross).
- Understanding what the required behaviour is / to perform the required behaviour.
- Possible misjudgement of distances and approaching speed.
- Understanding what the situation means: meaning of zebra crossing (long term memory).

Situation 2: Pedestrian crossing from right side at zebra crossing

Figure 8–2: Situation 2: Pedestrian crossing from right side at zebra crossing

Challenges for an older driver:

- This situation is probably less challenging for the older driver, because the pedestrian is right in front of the driver.
- However, there may be still a misjudgement of distance to pedestrian / pedestrian speed.
- Misjudging relationship of surrounding.

Situation 3: Pedestrian crossing from left side at zebra crossing

Figure 8–3:Situation 3: Pedestrian crossing from left side at zebra crossing

Challenges for an older driver:

- Perceiving of pedestrian since s/he is even more in the periphery (compared to previous situations).

- Saliency of pedestrian in such a situation is reduced, since s/he moves in periphery in front of vehicle that is maybe still moving as well or is standing still.
- Contrast with background limited.
    - Could lead to sudden surprise situation (cf. situation 1).

Situation 4: Pedestrian crossing from left side at zebra crossing hidden by oncoming vehicle

Figure 8–4:Situation 4: Pedestrian crossing from left side at zebra crossing hidden by oncoming vehicle

Challenges for an older driver:

- In general: in such a situation the pedestrian could not be perceived at all (also by regular drivers).
- Challenge is to anticipate / forecast the potential danger.
    - Slowing down / slowing down early enough in case there is a pedestrian crossing.
    - Older driver would need to perceive the zebra crossing at all / early enough and be aware of the danger of the situation that there might be a pedestrian crossing.
    - Saliency of pedestrian would be even lower with more traffic (in front, oncoming).

Situation 5+6: Group of pedestrians at right side of zebra crossing with one of them wanting to cross

Figure 8–5:Situation 5+6: Group of pedestrians at right side of zebra crossing with one of them wanting to cross

Challenges for an older driver:

- With a lot of by-standers, it’s even harder to perceive the intention of the pedestrian.
  - Overwhelming situation.
  - Extracting from a lot of motion, who has the intention to cross traffic in front of the driver.
  - Problem to extract the relevant cue.
  - Divert attention, detect environmental cues.
  - Requires anticipatory behaviour: slowing down to prepare for the situation.

Situation 7: Pedestrian crossing from right side with distance to zebra crossing

This situation refers to the case, where a pedestrian does not cross the zebra crossing in a right angle but rather in a slope.

Figure 8–6:Situation 7: Pedestrian crossing from right side with distance to zebra crossing

The situation becomes even more difficult with other pedestrians just walking on the sidewalk and one of them stepping out (right).

Challenges for an older driver:

- General challenge: Dealing with the reckless pedestrian, who shows unexpected behaviour.
- Situations which are outside the routine behaviour of older drivers may be an issue.
- Reaction of older driver (swerving) may be delayed due to reduced motor ability / reduced reaction time.
- Sudden reaction more difficult because of motor limitations.
    - Rigid reaction.

Situation 8+9: Pedestrian (child) wanting to cross the road without zebra crossing

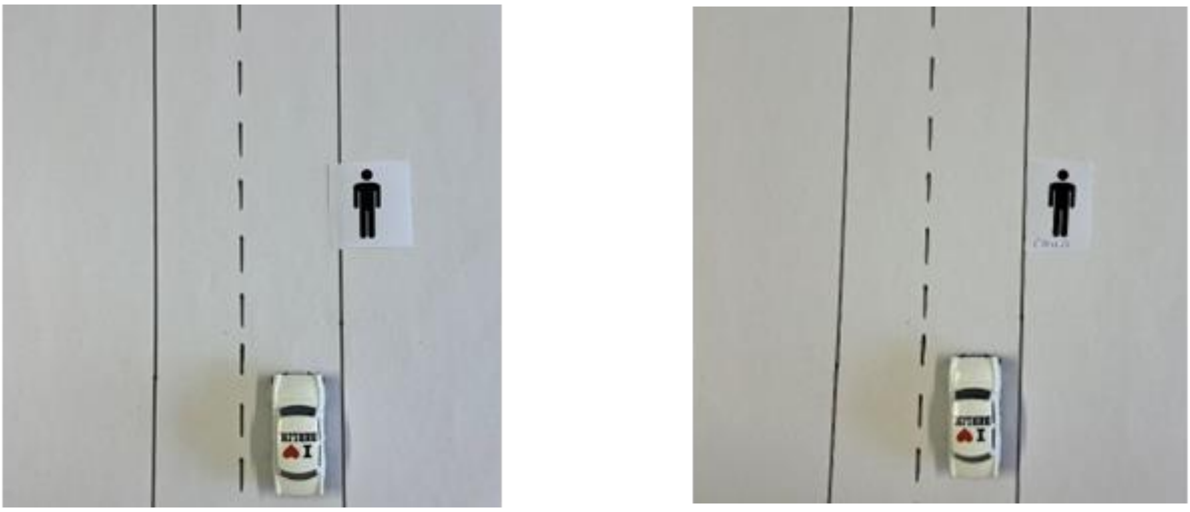

Figure 8–7:Situation 8+9: Pedestrian (child) wanting to cross the road without zebra crossing

Challenges for an older driver:

- In such a situation there is no prior signalization available to prepare for the situation
  - All the information comes from the pedestrian.
- Due to limits in vision.
  - Problems to perceive the pedestrian / pedestrian's intention (however, the assumption would be that an adult pedestrian without any restrictions would not cross if the driver does not slow down or somehow gives a sign to the pedestrian).
- But if the pedestrian is a child, who may misjudge the situation and show unexpected behaviour.
  - Older drivers could have problems to recognize pedestrian features (lack of visual acuity) from a distance (lack of visual acuity) – is it a child?
    - Height, posture, face, gaze.
  - This is however necessary for anticipatory behaviour (slowing down).