# Use case definition

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## Change History

| Version | Date | Name/Organisation | Description |
|---|---|---|---|
| 0.1 | 2023-02-17 | UAH | Preliminary structure and content of D1.2 with assignment of tasks for contributing partners. |
| 0.2 | 2023-03-03 | UAH | Reference use case description. |
| 0.3 | 2023-03-08 | UAH | Section 3 finished. |
| 0.4 | 2023-03-20 | UAH | Preliminary version finished. |
| 1.0 | 2023-03-23 | UAH | Revised by contributors. |
| 2.0 | 2023-04-13 | UAH | Revised by reviewers. |

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# 1. Executive Summary

The scope of this deliverable is to describe the use cases that will be developed and demonstrated in the framework of the HEIDI project. Use cases have been designed on the grounds of the user needs described in deliverable D1.1. Each use case has been divided into a number of experiments. All the experiments in a given use case will be demonstrated in simulation, while only a few of them will be demonstrated on a real vehicle. All use cases are designed with a view to maximizing safety and comfort while guaranteeing understandability and smooth interactions between road users and partially automated vehicles with different SAE levels. 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 Human Machine Interface (HMI) to be developed in the context of this project. This goal is aligned with HEIDI objectives #1, #2, #3, and #4.

As a main novelty with respect to other systems in the state of the art, HEIDI's use cases comprise interactions with road users with different levels of disability and/or attention, such as older drivers, disabled pedestrians, distracted drivers, and distracted pedestrians, as well as interactions with groups of pedestrians in signalized and unsignalized scenarios. Separate use cases have been devised for incrementally testing the internal HMI (iHMI), in use case 1 (UC1), the external HMI (eHMI), in use case 2 (UC2), and the fluid HMI, in use case 3 (UC3), to be developed in HEIDI. Every use case comprises several experiments intended to test the use case in different configurations or variants in order to cover a wide range of situations under a common pattern of interaction. The design and selection of the different experiments has been carried out attending to the relevance of the functionality to be addressed by means of the HMIs. Thus, an incremental approach has been followed in each use case. In a first step, we test a basic setup with respect to the core functionality of the respective HMI. Subsequently, we increase the complexity of the test cases by addressing different road user types and different numbers of road users. Finally, we also look at traffic situations which require communication on higher escalation levels according to higher urgency. The main goals of each of the use cases can differ. For example, one of the objectives addressed in UC1 is to focus on the tutoring system for elderly drivers. Amongst the goals of UC2 we focus on the interaction with the correct road user. In UC3, we consider the active support of cooperation as well as the resolution tracking of the optimal behaviour. An exhaustive analysis of uses cases has been conducted yielding a number of detailed experiments per use case. All the designed experiments will be considered in simulators while only a selected group of them will be demonstrated in a real vehicle. For each experiment, a detailed description has been provided by means of a table that includes the interacting agents, the targeted user needs, the graphical depiction of the scenario, and the sequence of events taking place in the scene.

**Keywords:** use cases, experiments, iHMI, eHMI, fluid cooperative HMI

# 2. Objectives

The main goal of this deliverable is to define the use cases and their associated experiments to be tested in the framework of HEIDI in order to maximize safety and comfort while guaranteeing understandability and smooth interactions between road users and automated vehicles with different SAE levels. 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 links and connections between the use cases and the different work packages have been properly established. Use case 1, dealing with the iHMI, is connected to WP2; use case 2 (eHMI) is connected to WP3; and use case 3 (holistic, fluid HMI) is linked to WP4. The definition of use cases, as provided in this deliverable (D1.2), will set the grounds for further work to be developed in WP2 (internal HMI to interact with the ego-driver), WP3 (external HMI to interact with vulnerable road users – VRUs, and external drivers), and WP4 (cooperative HMI). The definitions and descriptions in this document pave the way 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, timely, and effective manner. The cooperative HMI will be designed in a way that will allow to compensate for reduced user ability (age, distraction) and to still fulfil the identified user needs according to user type (driver, VRU) and automation level.

# 3. Selection process for use cases and selection criteria

This section provides a description of the rationale that was followed to select and design the use cases to be tested and validated in the HEIDI project.

## 3.1 Use Cases initial workshop

A first workshop was held to start the discussions about potential use cases. In this workshop, it was agreed to establish one use case per main WP (WP2 for the iHMI, WP3 for the eHMI, WP4 for the holistic or cooperative HMI). For each use case, several experiments (or configurations) would be defined on the grounds of the user needs, as described by HEIDI deliverable D1.1 [1]. Discussions for each use case were coordinated by the leaders of WP2 (for UC1), WP3 (for UC2), and WP4 (for UC3), respectively. For each use case, a number of experiments were initially proposed in a first step. In a second step, a selection was made by choosing a maximum of 8 experiments that will be considered on simulation and 4-5 experiments that will be demonstrated on a real vehicle. The criteria for rating the experiments in each use case was established as shown in ***Table 3-1***. The leaders of WP2 (VIF), WP3 (RUAS), and WP4 (HRI) coordinated the discussions in the framework of each use case.

**Table 3-1. Used criteria for rating HEIDI's use cases.**

| Category | Criteria |
|---|---|
| **Scientific/Technical** | Relevance for safety: special attention is given to the potential impact and severity of accidents taking place in the considered scenarios, accounting for typical/maximum velocities and the types of road users involved (pedestrians, older pedestrians, disabled pedestrians, older drivers, children). |
| | Frequency of occurrence: the considered use case can be a usual situation in day-to-day traffic, or it can be usual, but only in certain regions, or a corner case, or a rare event but relevant in terms of impact on safety. Major attention has been given to frequent situations and to corner cases with relevant impact. |
| | Relevance for traffic flow: the priority has been put on use cases with potential to increase traffic efficiency by leveraging more fluent interactions between traffic participants. |
| | Need for (benefit of) interactions with road users: potential interactions have been classified as essential, helpful, and not needed. The priority has been given to use cases dealing with situations where interaction is essential or those where interaction is helpful and very frequent. |
| | Expected impact on user acceptance: in this regard, the potential user acceptance on pedestrians, ego-driver, and other drivers has been considered. Aspects such as comfort, fluent interaction, and the feeling of being understood and respected have been considered. |
| **Project related** | Demonstration on demo vehicles (possible / not possible). |
| | Demonstration on simulators (possible / not possible). |

The framework for discussion encompassed the three use cases under consideration in the light of the different levels of automation as described by the SAE (Society of Automotive Engineers) [2]. This involves the use of different HMIs (iHMI and eHMI) for interacting with different types of road users (regular, distracted, impaired, older) by means of vehicles exhibiting levels SAE 0-2 (fully responsible driver), SAE 3 (Fallback-ready driver), and SAE 4-5 (out-of-the-loop driver). Discussions taking place in the initial workshop are graphically compiled in *Figure 3-1*.

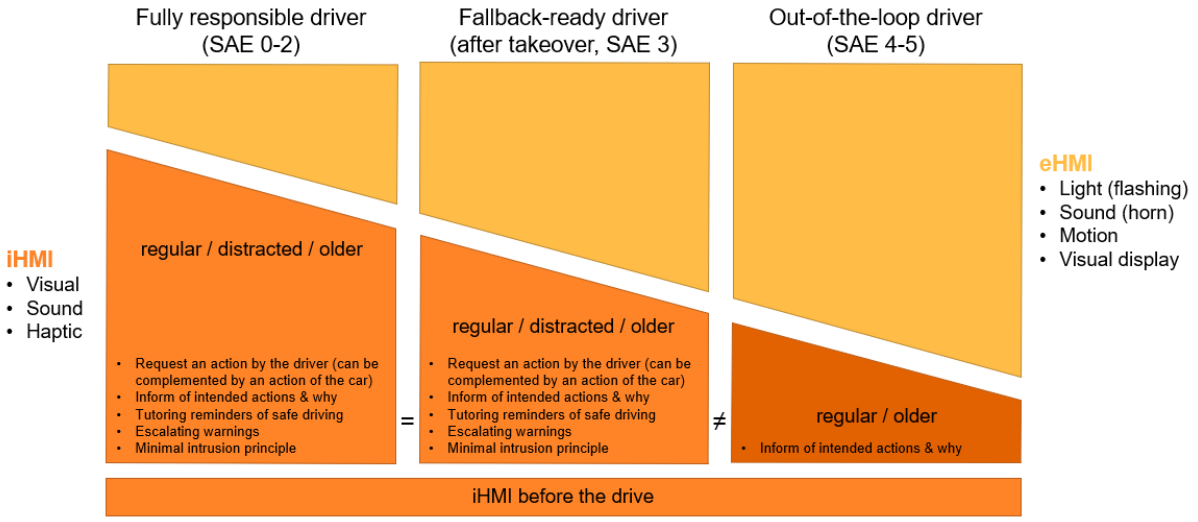


Figure 3-1. Interactions between road users and automated vehicles with different SAE levels in HEIDI

Given that use cases are interlinked, in the initial workshop it was also agreed to undertake a top-down approach. Accordingly, experiments for use case 3 (dealing with the cooperative HMI – cHMI) would set a baseline for the selection and design of experiments for use case 1 (iHMI) and use case 2 (eHMI). The concept is graphically illustrated in *Figure 3-2*.

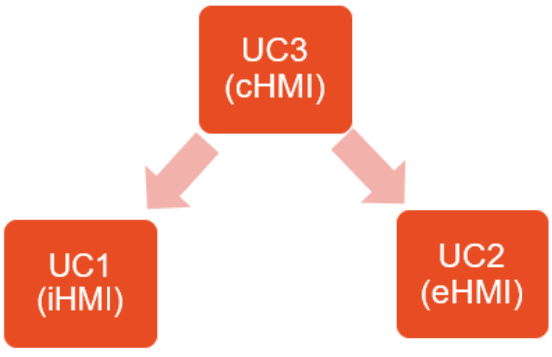


Figure 3-2. Hierarchical approach for selecting and designing experiments in use cases

Another discussion was focused on the negotiation process established between the automated vehicle and other road users, such as, for example, pedestrians. This negotiation process can derive into different forms of interactions, depending on the degree of cooperation of the different actors. This discussion set the grounds for establishing the difference between situation and experiment (or configuration). The concept is graphically illustrated in *Figure 3-3*.

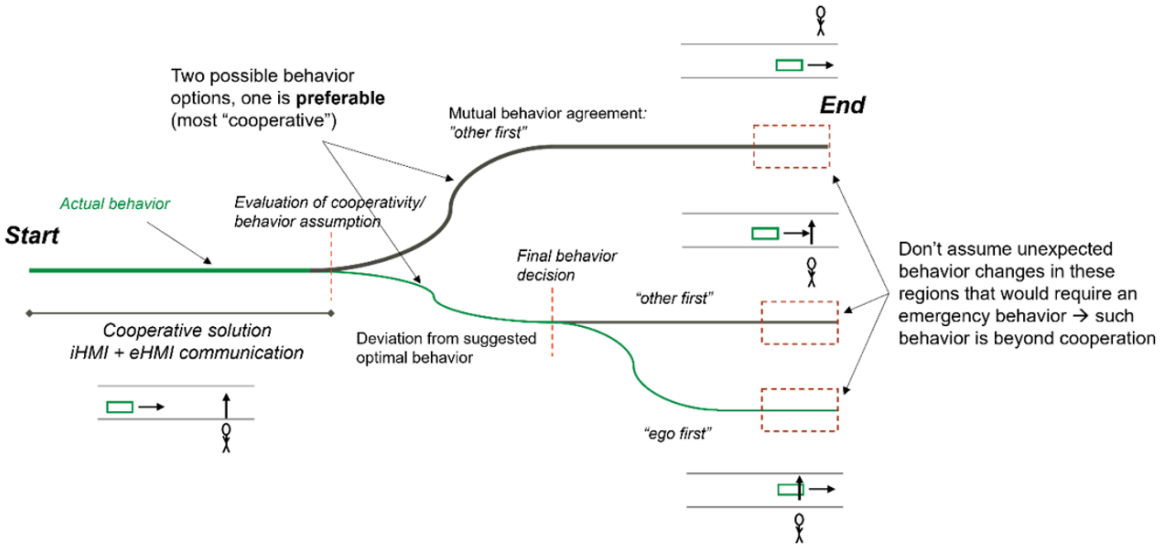


Figure 3-3. Cooperative interaction between partially automated vehicle and pedestrian. Analysis of possible situations

In the framework of this discussion, priorities for the ego-vehicle and external road users (pedestrians, in this specific example) were also analysed for crossings of different types ruled by traffic lights, unsignalized, and zebra crossing. A possible characterization of such priorities is depicted in *Figure 3-4*. The grey zone provided in this figure represents the area for cooperation between the agents involved in the interaction. As can be appreciated, there are still some open questions, such as the characterization of the priority for pedestrians at zebra crossings as a function of the velocity of the ego-vehicle.

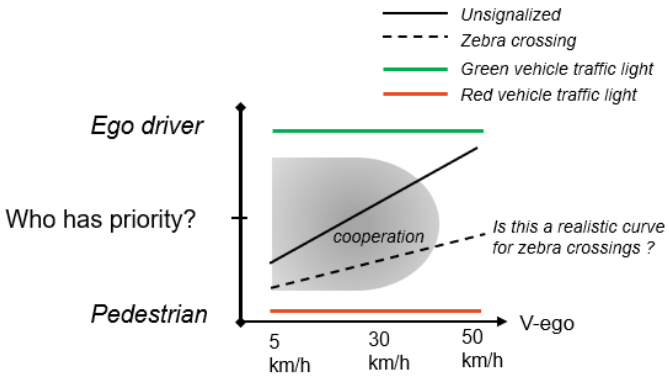


Figure 3-4. Analysis of priorities between ego-driver and pedestrians

The initial workshop paved the way for the selection and design of use cases and experiments. Specific workshops took place afterwards in the framework of each use case.

## 3.2 Situation vs Experiment

When selecting and designing the use cases, the HEIDI project has considered several situations involving different road users and vehicles. Every situation provides a singular framework where road users interact with the ego-vehicle in a given manner. However, for every situation, the action may develop in different ways depending on the behaviour of the road users involved in the situation. For example, a situation may involve an automated car (ego-vehicle) equipped with an eHMI and a pedestrian approaching the road curb. Depending

on the decisions made by the pilot system of the ego-vehicle and by the pedestrian, the situation may evolve into an action where the ego-vehicle passes first (not yielding to the pedestrian) or into an action where the ego-vehicle yields to the pedestrian (so that the pedestrian passes first). Another possibility is that the pedestrian does not have the intention to cross at all and refuses to cross even if the ego-vehicle yields. All these possibilities can be framed into different experiments. In a way, experiments can be considered as different instantiations or different evolutions of the same situation under different operational conditions. Thus, the same situation can derive into multiple different experiments. Accordingly, the description of HEIDI's use cases will be carried out based on experiments, some of which may refer to the same situation in different conditions.

## 3.3 Use Case 1 – Workshop and discussion

The workshop for use case 1 was coordinated by VIF, leader of WP2. In this case, experiments dealing with the use of the internal HMI (iHMI) alone were considered. These experiments were discussed in the context of an ego-vehicle with SAE level 0-2, meaning that the ego-driver is fully responsible of the driving task. Four main goals were established for selecting and designing the experiments in use case 1.

- Account for regular/distracted drivers' behaviour and responses, aiming at maximizing fluidity.
- Escalate interaction (adaptability).
- Maximize interpretability and minimize mental load (low obtrusiveness).
- Long term benefit and use for older drivers (adaptive tutoring).

With these goals in mind, a preliminary set of situations was discussed, leading to seven initial proposals, as graphically illustrated in *Figure 3-5* (the detailed description of the finally selected situations/experiments will be described in section 4.1).

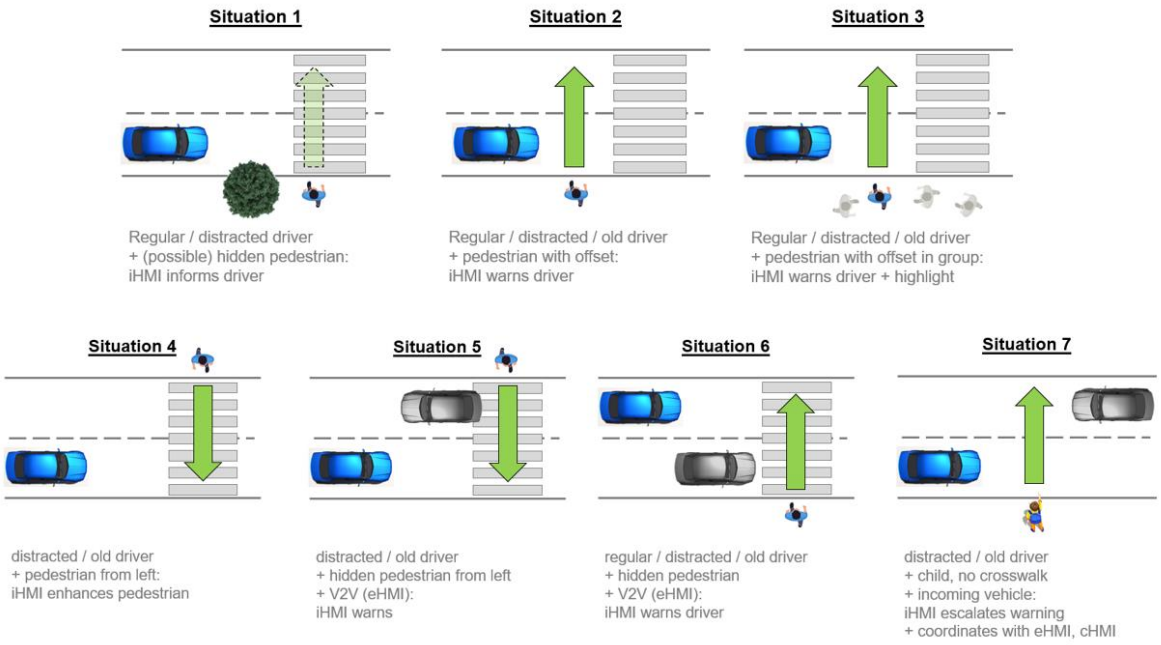


Figure 3-5. Preliminary analysis of situations in use case 1

In the course of the discussion, a controversy arose regarding the consideration of situations that involved the use of external HMIs on external cars (different from the ego-vehicle) participating in the use case. Eventually, it was decided that those situations were out of the scope of HEIDI and, consequently, they were discarded. Instead, different experiments for the remaining situations were considered in the final selection process.

## 3.4 Use Case 2 – Workshop and discussion

Following a similar course of action, a preliminary proposal of eight experiments was carried out for use case 2 (dealing with the use of the external HMI). The set of initial proposals is depicted in *Figure 3-6* (the detailed description of the finally selected situations/experiments will be described in section 4.2).

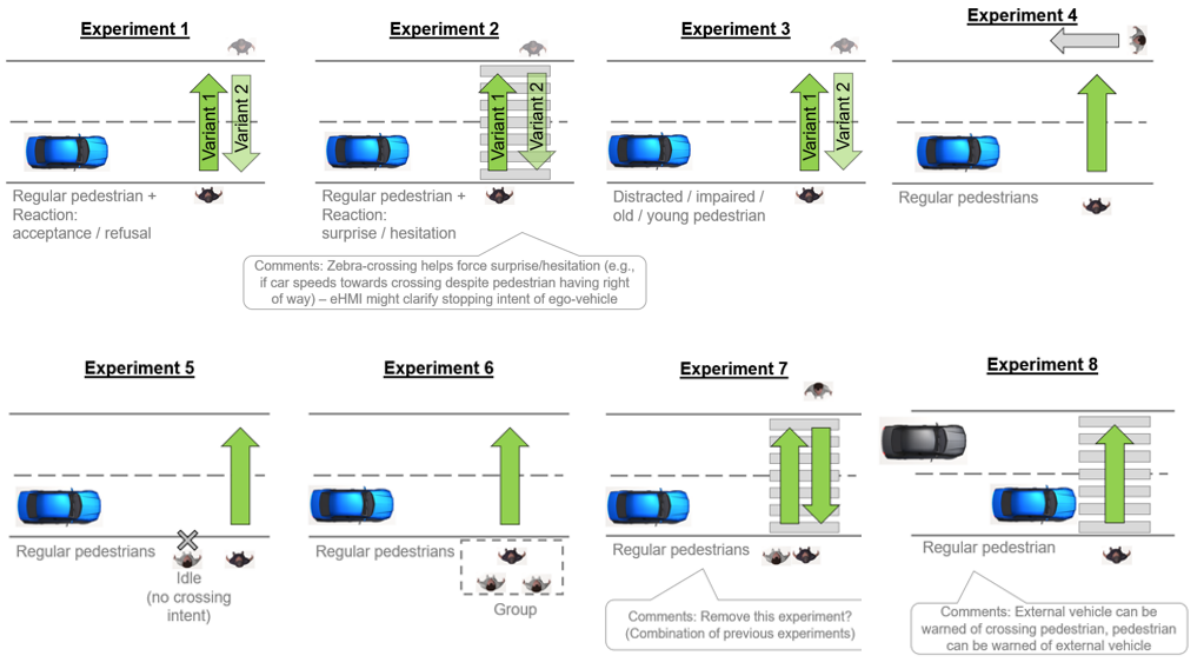


Figure 3-6. Preliminary analysis of experiments in use case 2

During the discussion, a controversy was raised in experiment 8, given that it involves an external vehicle (grey vehicle in the picture above). In such experiment, the ego-vehicle has the possibility of activating a frontal external HMI, for interacting with the pedestrian, and a rear external HMI, for interacting with the external driver. The detailed analysis of this experiment is provided in section 4.2.

## 3.5 Use Case 3 – Workshop and discussion

As in the previous cases, a preliminary proposal of eight experiments was carried out for use case 3, dealing with the use of the fluid, cooperative HMI. The set of initial proposals is depicted in Figure 3-7 (the detailed description of the finally selected situations/experiments will be described in section 4.3). This use case deals with ambiguous scenarios which lack a clear resolution, meaning that those scenarios exhibit low utility, low efficiency, low comfort, and high risk without the HEIDI system. The scenarios include unsignalized crossing areas and are expected to have low asymmetry. The main goal is to demonstrate the active benefit that HEIDI

provides by facilitating cooperation and resolution of ambiguous situations. Some partners raised concerns about experiment #7, as it must be ensured that pedestrians have the right of way at zebra crossings at all times, which is why experiment #8 will not be explicitly tested. The exact configuration of this experiment is described in section 4.3.

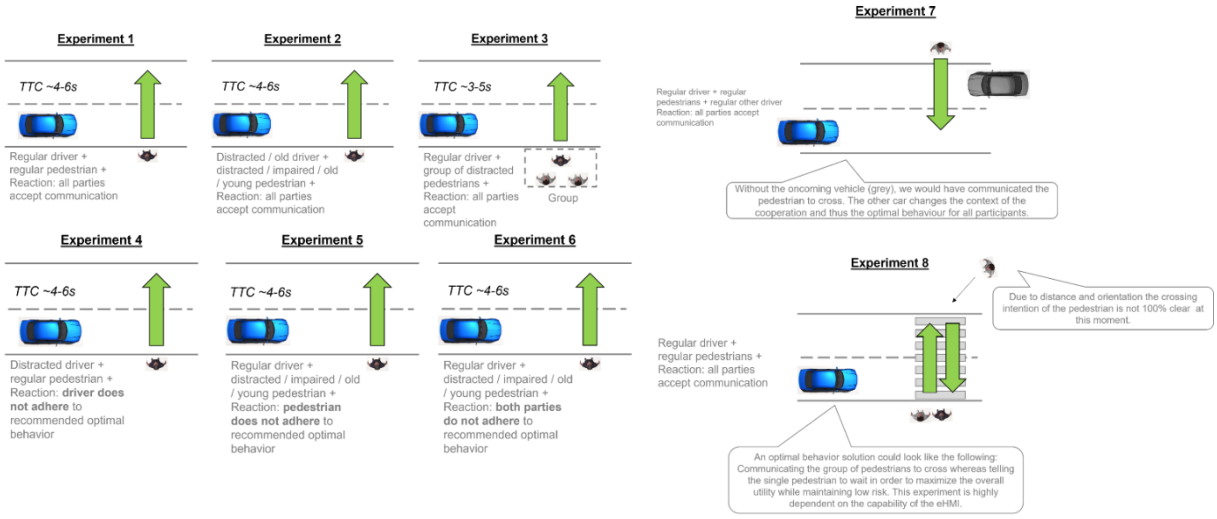


Figure 3-7. Preliminary analysis of experiments in use case 3

## 3.6 Methodology to describe use cases

A template was designed to provide use case descriptions in a tabular format. This template has been used to describe the different experiments in each use case, as shown in ***Table 3-2***. The template provides two types of graphical descriptions for each experiment. On the one hand, a graphical diagram depicts the environment where the action develops as well as the actors involved. On the other hand, a sequence diagram shows the timing of the different events and interactions taking place along a time frame.

**Table 3-2: Use Case template.**

| Use Case | Name of use case |
|---|---|
| **Experiment** | Provide experiment number for each use case. |
| **SAE Level** | SAE Level 0 - 5. |
| **Environment** | Urban; road; intersection; crossing; |
| **Description** | Extended description of use case experiment. |
| **Graphical diagram** | Graphical diagram depicting the environment and actors. |
| **Sequence diagram** | Sequence diagram showing the timing of events taking place. |
| **Relevance** | Describe relevance of experiment in the framework of the use case in terms of road safety and fluent interactions between road users and automated vehicles. |
| **Addressed Interaction Actors** | Pedestrian (regular, distracted, impaired, older, child); ego-driver (regular, distracted, impaired, older); other drivers. |
| **Addressed user needs (D1.1)** | Reference to user needs as described in D1.1. |

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| **Validation** | Evaluation platform to be used: simulator, proving ground, real driving. |

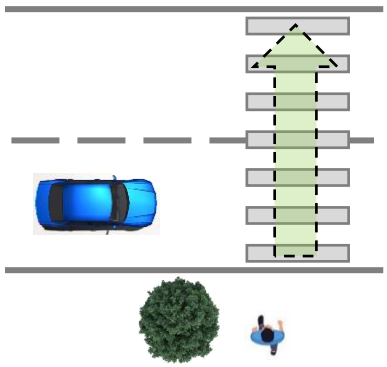
# 4. Description of Use Cases

This section provides a detailed description of the different use cases that will be evaluated in the HEIDI project. Three main use cases have been devised, denoted as UC1 (Use Case 1), UC2 (Use Case 2), and UC3 (Use Case 3), respectively. For each use case, a number of experiments have been provided to cover different possible situations and configurations.

## 4.1 Use Case 1

UC1 has been devised to test and validate different situations and experiments dealing with interactions between the ego-vehicle and the ego-driver by means of an internal HMI (iHMI). The experiments that have been designed in the framework of UC1 are described in detail in the next sections.

### 4.1.1 Experiment 1: Interaction with a regular hidden pedestrian at crosswalk

| Use Case | Use Case 1 |
|---|---|
| **Experiment** | #1. Interaction with regular hidden pedestrian at crosswalk. |
| **SAE Level** | 0-2 |
| **Environment** | Urban. |
| **Description** | A SAE Level 0-2 ego vehicle is driving along a two-way road, which has one lane per driving direction, in an urban environment. No other vehicles are present. The ego vehicle is approaching a pedestrian crosswalk where an obstacle (e.g., trees, parked cars) is hiding the pedestrian. Thus, the driver nor the pedestrian detection sensor may be able to detect the pedestrian and/or the pedestrian's intention to cross. The pedestrian is a regular pedestrian with no visible impairments and wishes to cross the road. The iHMI informs/alerts the driver that there is a crosswalk with potential pedestrians. |
| **Graphical diagram** |  |
| **Sequence diagram** | |

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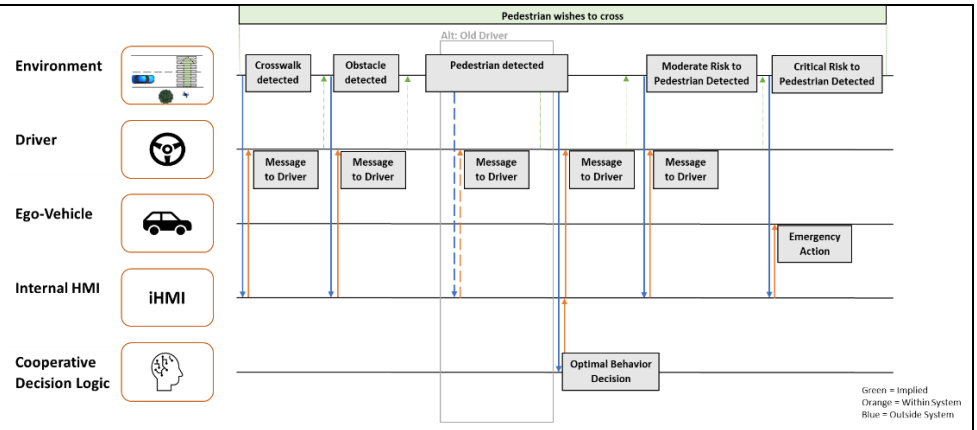
| |  |
| **Relevance** | This experiment is meant to assess the interaction between manually driven vehicles and hidden pedestrians at crosswalks. The iHMI must warn the driver about such risks when there are obstacles in the area of a crosswalk that could be hiding a pedestrian. The interaction is intended to enhance road safety while bringing awareness to the drivers about potential risky situations. |
| **Addressed Interaction Actors** | Ego-Driver: Regular, Distracted, Old<br>Pedestrian: Regular |
| **Addressed user needs (D1.1)** | The experiment addresses the driver´s need to be aware of and understand their surroundings, including other vehicles and pedestrians, via their own cognitive capacity and supplemented by the vehicle's assistance in the form of clear and concise warnings/information alerts about the current situation. Hereby, the object hiding the pedestrian is a challenging factor for the driver.<br>Older drivers additionally have a need for additional information about the situation. Distracted drivers have the additional needs for more urgent warnings. |
| **Validation** | Simulator, proving ground TRL6. |

### 4.1.2 Experiment 2: Interaction with a regular pedestrian at crosswalk with offset

| Use Case | Use Case 1 |
|---|---|
| **Experiment** | #2. Interaction with a regular pedestrian at crosswalk with an offset. |
| **SAE Level** | 0-2 |
| **Environment** | Urban. |
| **Description** | A SAE Level 0-2 ego-vehicle is driving along a two-way road, which has one lane per driving direction, in an urban environment. No other vehicles are present. The ego-vehicle is approaching a pedestrian crosswalk. There is a pedestrian by the curb on the right-hand side at an offset to the bounds of the crosswalk. The pedestrian is a regular pedestrian with no visible impairments and wishes to cross the road. The ego-vehicle must inform/alert the driver that there is a pedestrian wishing to cross in the case of older drivers. |

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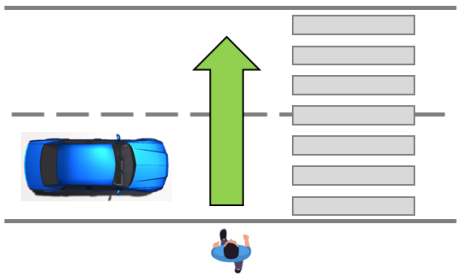
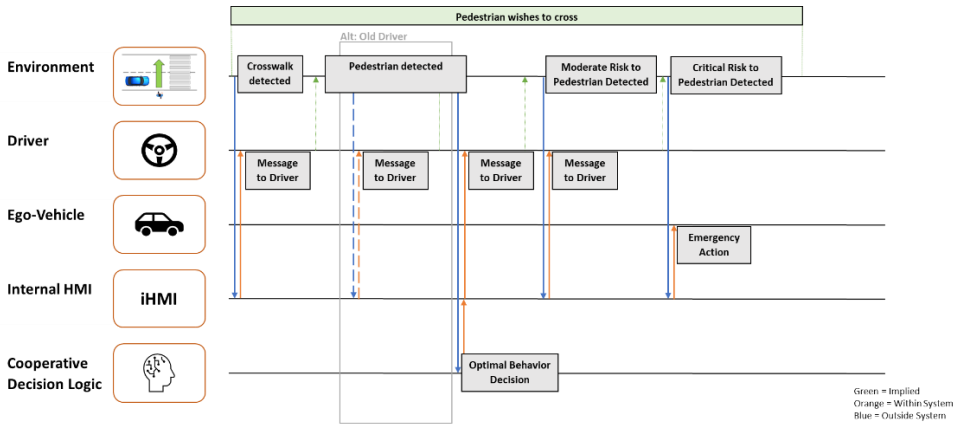
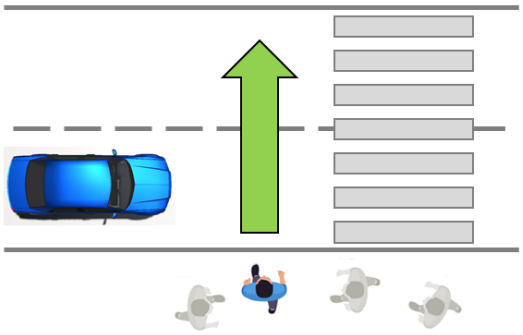
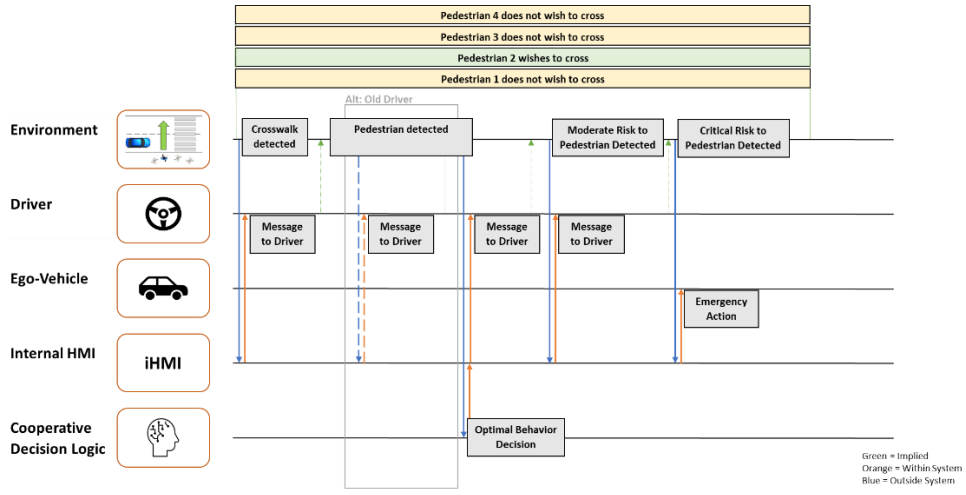
|---|---|
| **Graphical diagram** |  |
| **Sequence diagram** |  |
| **Relevance** | This experiment is meant to assess the interaction between manually driven vehicles and pedestrians located at an offset to a crosswalk. As most pedestrians do not cross within the bounds of the crosswalk, the ego-vehicle driver must be aware that a pedestrian wishes to cross regardless of the position of the designated crosswalk zone. The ego-vehicle driver accordingly will need to respond appropriately to the pedestrian's behaviour and the critically reduced TTC time allowed due to the offset. The iHMI needs to provide an additional warning to older drivers about the pedestrian wanting to cross the road. |
| **Addressed Interaction Actors** | Ego-driver: Regular, Distracted, Old<br>Pedestrian: Regular |
| **Addressed user needs (D1.1)** | The experiment addresses the driver´s need to be aware of and understand their surroundings, including other vehicles and pedestrians, via their own cognitive capacity and supplemented by the vehicle's assistance in the form of clear and concise warnings/information alerts about the current situation. Hereby, the offset of the pedestrian crossing position from the crosswalk is a challenging factor for the driver.<br>Older drivers additionally have a need for additional information about the situation. Distracted drivers have the additional needs for more urgent warnings. |
| **Validation** | Simulator, proving ground TRL6. |

### 4.1.3 Experiment 3: Interaction with a pedestrian within a group at an offset to a crosswalk

| Use Case | Use Case 1 |
|---|---|
| **Experiment** | #3. Interaction with a regular pedestrian within a group at an offset to a crosswalk. |
| **SAE Level** | 0-2 |
| **Environment** | Urban. |
| **Description** | A SAE Level 0-2 ego-vehicle is driving along a two-way road, which has one lane per driving direction, in an urban environment. No other vehicles are present. The ego-vehicle is approaching a pedestrian crosswalk. There is a pedestrian within a group of other pedestrians by the curb on the right-hand side at an offset to the bounds of the crosswalk. The pedestrian is a regular pedestrian with no visible impairments and wishes to cross the road. |
| **Graphical diagram** |  |
| **Sequence diagram** |  |
| **Relevance** | This experiment is meant to assess the interaction between drivers and a group of pedestrians in crossing situations with crosswalks at an offset. The ego-vehicle driver must be able to detect that one pedestrian out of the group has the intention to cross before the bounds of the crosswalk. In consequence the driver needs to react appropriately to the pedestrian´s behaviour and quickly enough to account for the lower TTC. The iHMI needs to make sure that the driver is aware that one of the pedestrians |

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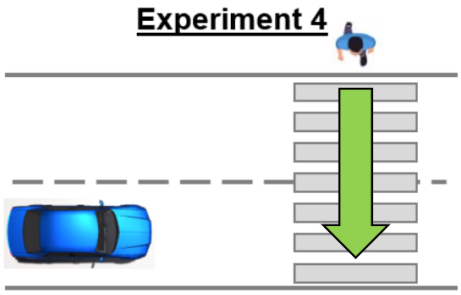
| | has the intention to cross and to ensure that the driver handles the situation safely. This is especially challenging for old and distracted drivers. |
| **Addressed Interaction Actors** | Ego-driver: Regular, Distracted, Old<br>Pedestrian: Regular |
| **Addressed user needs (D1.1)** | The experiment addresses the driver´s need to be aware of and understand their surroundings, including other vehicles and pedestrians, via their own cognitive capacity and supplemented by the vehicle's assistance in the form of clear and concise warnings/information alerts about the current situation. Hereby, the presence of several pedestrians and the offset of the pedestrian crossing position from the crosswalk is a challenging factor for the driver.<br>Older drivers additionally have a need for additional information about the situation. Distracted drivers have the additional needs for more urgent warnings. |
| **Validation** | Simulator, proving ground TRL6. |

### 4.1.4 Experiment 4: Interaction with a pedestrian at a crosswalk

| Use Case | Use Case 1 |
|---|---|
| **Experiment** | #4. Interaction with a pedestrian at a crosswalk. |
| **SAE Level** | 0-2 |
| **Environment** | Urban. |
| **Description** | A SAE Level 0-2 ego vehicle is driving along a two-way road, which has one lane per driving direction. The environment is urban. The ego vehicle is approaching a crosswalk with a pedestrian on the left side. The pedestrian wishes to cross the road. A regular driver should see the pedestrian and their intention to cross, however for an older or distracted driver there may be an issue. No other vehicles than the ego vehicle is present. |
| **Graphical diagram** |  <br>Regular / distracted / old driver<br>+ pedestrian from left:<br>iHMI enhances pedestrian |

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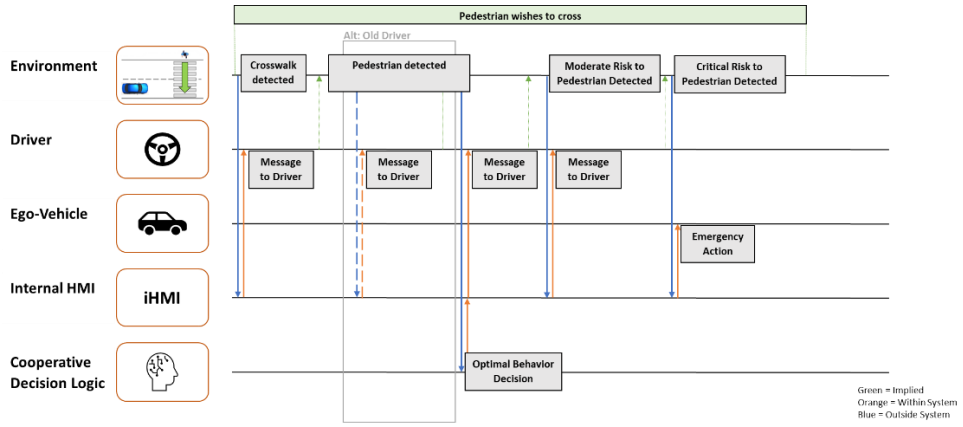
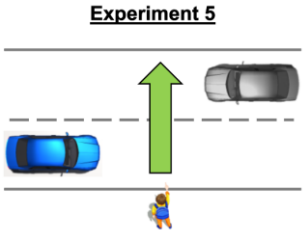
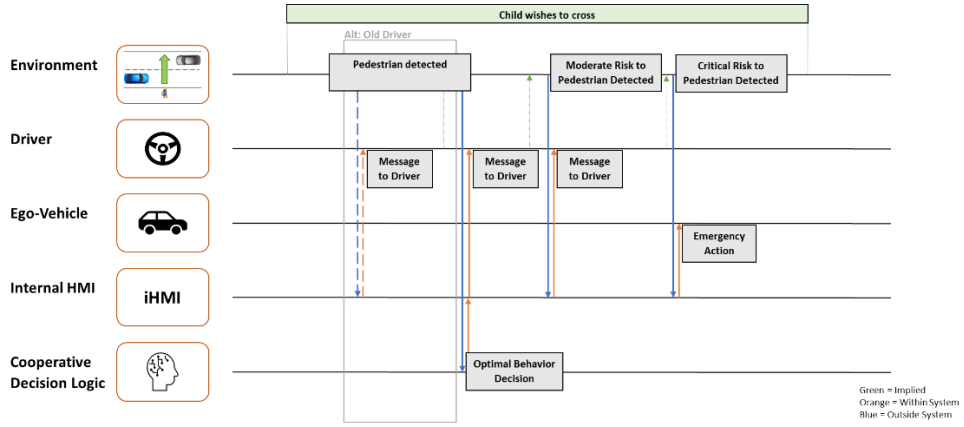
|---|---|
| **Sequence diagram** |  |
| **Relevance** | This experiment is meant to assess the interaction between drivers and pedestrians in crossing situations with crosswalks. The ego-vehicle driver must be able to react appropriately to the pedestrian´s behaviour. The iHMI needs to make sure that the driver is aware of the pedestrian and handles the situation safely. This is especially challenging for old and distracted drivers. |
| **Addressed Interaction Actors** | Ego-driver: Regular, Distracted, Old<br>Pedestrian: Regular |
| **Addressed user needs (D1.1)** | The experiment addresses the driver´s need to be aware of and understand their surroundings, including other vehicles and pedestrians, via their own cognitive capacity and supplemented by the vehicle's assistance in the form of clear and concise warnings/information alerts about the current situation.<br>Older drivers additionally have a need for additional information about the situation. Distracted drivers have the additional needs for more urgent warnings. |
| **Validation** | Simulator, proving ground TRL6. |

### 4.1.5 Experiment 5: Interaction with a child in a situation without crosswalk

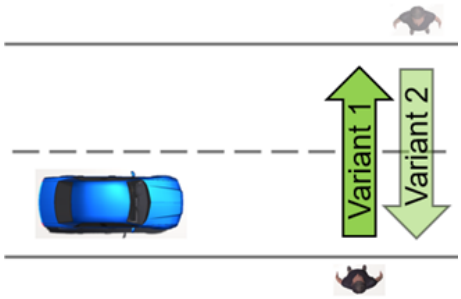
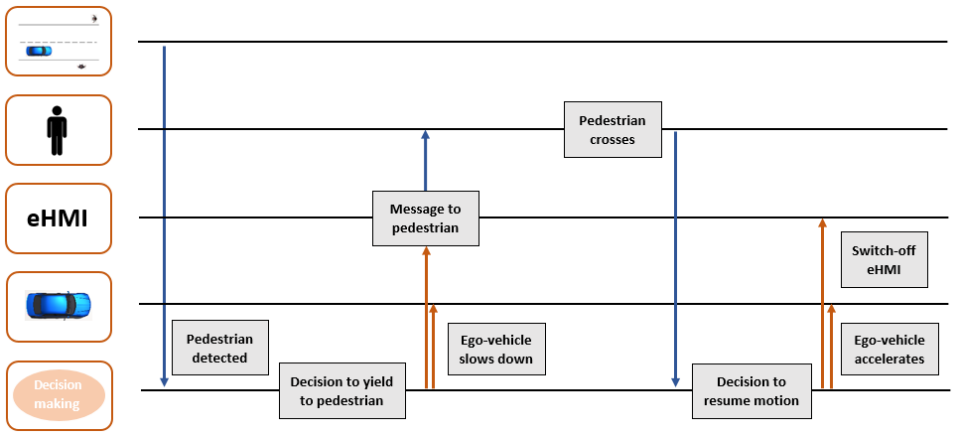
| Use Case | Use Case 1 |
|---|---|
| **Experiment** | #5. Interaction with a child in a situation without crosswalk |
| **SAE Level** | 0-2 |
| **Environment** | Urban |
| **Description** | A SAE Level 0-2 ego vehicle is driving along a two-way road, which has one lane per driving direction. The environment is urban. The ego vehicle is approaching a standing pedestrian. The pedestrian is a child. The child is in an area of the road where there is no signalized crosswalk. The child wishes to cross the road. A second vehicle is approaching the situation on the oncoming lane. The ego-vehicle must alert the driver that there is a child with higher likelihood of unforeseen actions. |

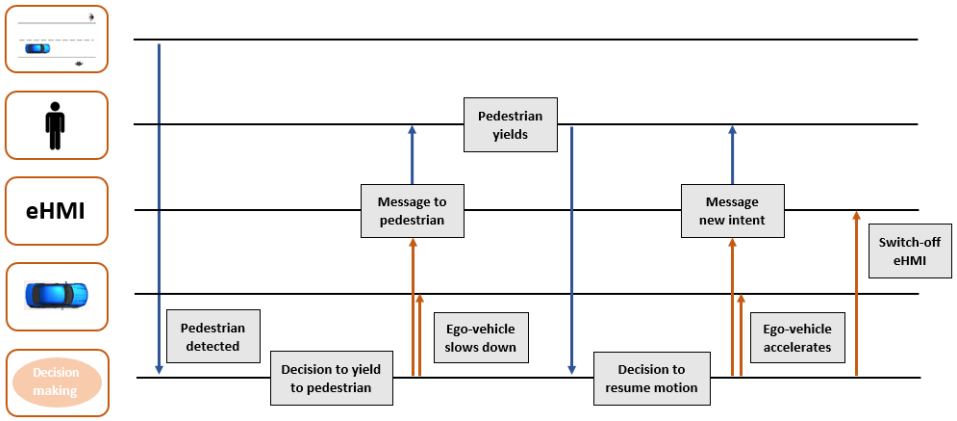
| | |
|---|---|
| **Graphical diagram** |  <br>Regular / distracted / old driver<br>+ child, no crosswalk<br>+ incoming vehicle:<br>iHMI escalates warning<br>+ coordinates with eHMI, cHMI |
| **Sequence diagram** |  |
| **Relevance** | This experiment is meant to assess the interaction between drivers and children in crossing situations without crosswalks. The driver of the ego-vehicle must be able to react appropriately to the child´s, possibly unexpected, behaviour. The iHMI needs to make sure that the driver is aware of the child and handles the situation safely. Hereby the challenge is increased for old and distracted drivers. |
| **Addressed Interaction Actors** | Ego-driver: Regular, Distracted, Old<br>Pedestrian: Child |
| **Addressed user needs (D1.1)** | The experiment addresses the driver´s need to be aware of and understand their surroundings, including other vehicles and pedestrians, via their own cognitive capacity and supplemented by the vehicle's assistance in the form of clear and concise warnings/information alerts about the current situation. Hereby, the presence of a child and the lack of a crosswalk is a challenging factor for the driver.<br>Older drivers additionally have a need for additional information about the situation. Distracted drivers have the additional needs for more urgent warnings. |
| **Validation** | Simulator. |

## 4.2 Use Case 2

UC2 has been devised to test and validate different situations and experiments dealing with interactions between automated vehicles and external road users by means of an external HMI (eHMI). The experiments that have been designed in the framework of UC2 are described in detail in the next sections.

### 4.2.1 Experiment 1: Accepting / refusing VRU detection and interaction

| Use Case | Use Case 2 |
|---|---|
| **Experiment** | #1. Accepting / refusing VRU detection and interaction. |
| **SAE Level** | 3 |
| **Environment** | Urban. |
| **Description** | A SAE Level-3 ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches a standing pedestrian, located either on the right or left road curb. The pedestrian is regular (not suffering any perceived impairment condition). The pedestrian is looking for eye contact with the driver of the ego-vehicle and is oriented towards the road in a position that indicates a clear intention to start crossing the road. The ego-vehicle will yield to the pedestrian, while communicating its yielding intention to the pedestrian by means of its external HMI (eHMI). The pedestrian will then either accept and cross or signalize his own yielding intention resulting in the ego-vehicle going first. |
| **Graphical diagram** |  |
| **Sequence diagram** | Acceptance of pedestrian:<br>  |

| | |
|---|---|
| | Refusal of pedestrian:<br>  <br> |
| **Relevance** | The experiment is meant to address the interaction between automated vehicles and pedestrians at non-signalized crossings. The acceptance or refusal of the pedestrian to the eHMI and thus the intent of the ego-vehicle will be detected. This valuable information can then be used to improve understanding and trust between both parties and thus increase traffic safety while also optimizing the flow of traffic. |
| **Addressed Interaction Actors** | Pedestrian (regular); ego-vehicle. |
| **Addressed user needs (D1.1)** | • Pedestrians must be robustly perceived by automated vehicles at all times.<br>• Use of appropriate and unequivocal vehicle signalling (as a means to acknowledge the presence of the pedestrian).<br>• Interactions with automated vehicles must lead to a smaller number of dangerous behaviours.<br>• Smooth and intuitive interactions with automated vehicles.<br>• Improved perception of comfort and enhanced feeling of respect when interacting with vehicles. |
| **Validation** | Simulator; proving ground TRL5. |

### 4.2.2 Experiment 2: Surprised / hesitant VRU detection and interaction

| Use Case | Use Case 2 |
|---|---|
| **Experiment** | #2. Surprised / hesitant VRU detection and interaction. |
| **SAE Level** | 3 |
| **Environment** | Urban, crossing. |
| **Description** | A SAE Level-3 ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, approaching a pedestrian crossing. The ego-vehicle approaches a standing pedestrian, located either on the right or left road curb. The pedestrian is regular (not suffering any perceived impairment condition). The pedestrian is looking for eye contact |

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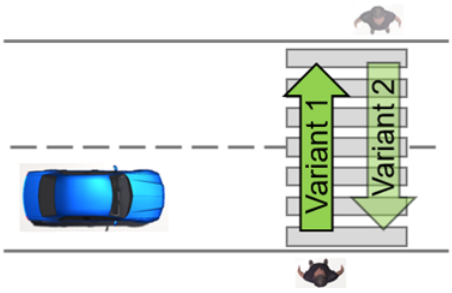
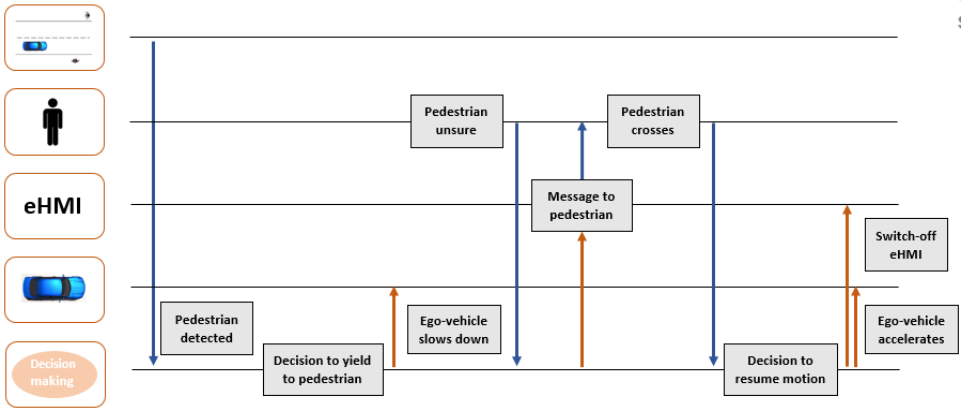
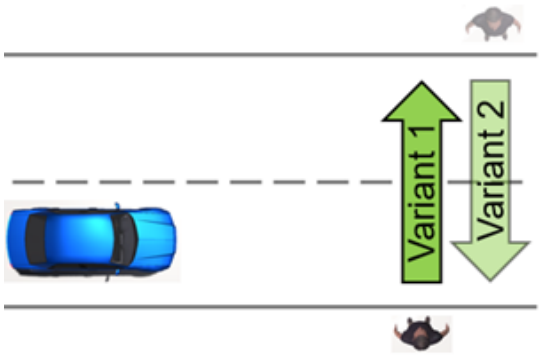
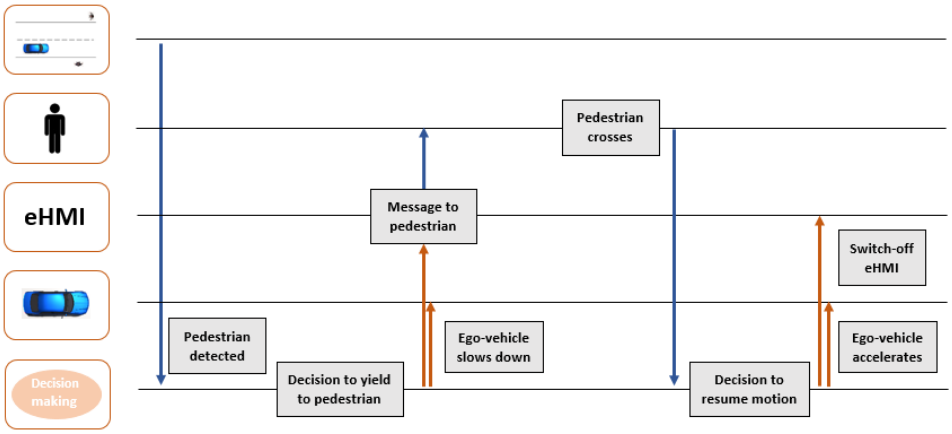
| | with the driver of the ego-vehicle and is oriented towards the road in a position that indicates a clear intention to start crossing the road. The ego-vehicle will yield to the pedestrian. However, due to only a small reduction in speed, the pedestrian is surprised and/or hesitant to cross. The ego-vehicles' yielding intention will be shown to the pedestrian by means of its external HMI (eHMI). Thus, the pedestrian can be reassured of being recognized and the vehicles intent. The pedestrian will then cross. |
| **Graphical diagram** |  |
| **Sequence diagram** |  |
| **Relevance** | The experiment is meant to address the interaction between automated vehicles and pedestrians at signalized crossings. The ego-vehicle needs to stop, if there is a possibility that the pedestrian wants to cross, thus there should be no need for any addition interaction. However, in reality, the pedestrian only starts walking when the vehicle is standing still and waiting. Thus, there is potential to optimize the traffic flow by clearly showing the stopping intent of ego-vehicle and recognition to the pedestrian. By evaluating the surprise and hesitation of the pedestrian such eHMI signals can be sent when required. Thus, improving understanding and trust between both parties, while also optimizing the flow of traffic. |
| **Addressed Interaction Actors** | Pedestrian (regular); ego-vehicle. |
| **Addressed user needs (D1.1)** | • Pedestrians must be robustly perceived by automated vehicles at all times.<br>• Use of appropriate and unequivocal vehicle signalling (as a means to acknowledge the presence of the pedestrian).<br>• Interactions with automated vehicles must lead to a smaller number of dangerous behaviours.<br>• Smooth and intuitive interactions with automated vehicles. |

| | |
|---|---|
| | • Improved perception of comfort and enhanced feeling of respect when interacting with vehicles. |
| **Validation** | Simulator. |

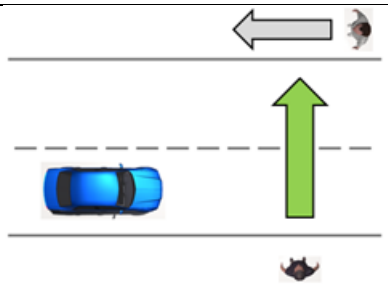
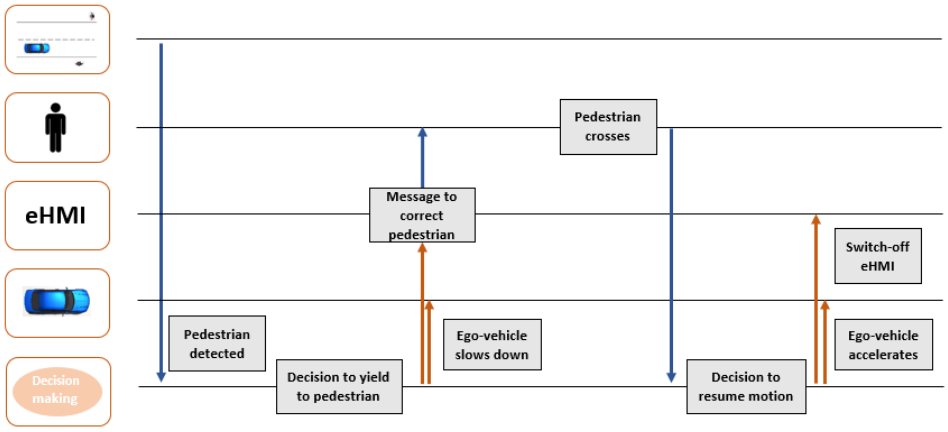
### 4.2.3 Experiment 3: VRU attribute detection and interaction

| Use Case | Use Case 2 |
|---|---|
| **Experiment** | #3. VRU attribute detection and interaction. |
| **SAE Level** | 3 |
| **Environment** | Urban. |
| **Description** | A SAE Level-3 ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches a standing pedestrian, located either on the right or left road curb. The pedestrian is either distracted, impaired, elderly or a child. The pedestrian is oriented towards the road in a position that indicates a clear intention to start crossing the road. The ego-vehicle will yield to the pedestrian, while communicating its yielding intention to the pedestrian by means of its external HMI (eHMI). The timing and severity of eHMI used will depend on the pedestrian type. |
| **Graphical diagram** |  |
| **Sequence diagram** |  |
| **Relevance** | The experiment is meant to address the interaction between automated vehicles and pedestrians at non-signalized crossings. For this interaction, certain pedestrian attributes can influence when to show messages and what type of messages an eHMI should display. This can have an impact on the understanding and trust of a non-regular pedestrian towards the ego- |

| | |
|---|---|
| | vehicles intent. By detecting such pedestrian attributes and adjusting how the eHMI communicates, misunderstandings can be avoided, and dangerous situations reduced. |
| **Addressed Interaction Actors** | Pedestrian (distracted / impaired / elderly / child); ego-vehicle. |
| **Addressed user needs (D1.1)** | • Pedestrians must be robustly perceived by automated vehicles at all times.<br>• Use of appropriate and unequivocal vehicle signalling (as a means to acknowledge the presence of the pedestrian).<br>• Interactions with automated vehicles must lead to a smaller number of dangerous behaviours.<br>• Smooth and intuitive interactions with automated vehicles.<br>• Improved perception of comfort and enhanced feeling of respect when interacting with vehicles. |
| **Validation** | Simulator; proving ground TRL5. |

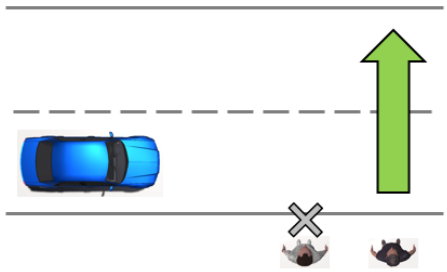
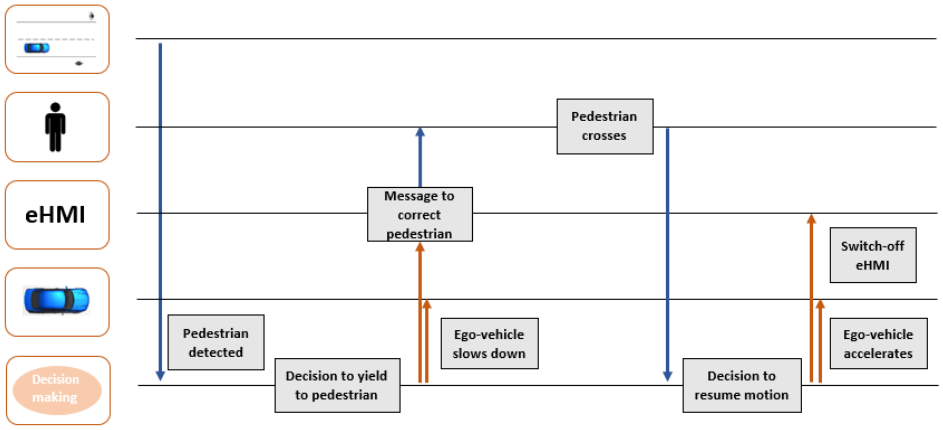
### 4.2.4 Experiment 4: Detection of relevant interaction partner on different roadsides

| Use Case | Use Case 2 |
|---|---|
| **Experiment** | #4. Detection of relevant interaction partner on different roadsides. |
| **SAE Level** | 3 |
| **Environment** | Urban. |
| **Description** | A SAE Level-3 ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches a standing pedestrian, located by the road curb at the right-hand side, and a walking pedestrian located at the left-hand side. The two pedestrians are regular (not suffering any perceived impairment condition). The pedestrian standing on the right side is looking for eye contact with the driver of the ego-vehicle and is oriented towards the road in a position that indicates a clear intention to start crossing the road. The pedestrian on the left side is walking along the sidewalk in a direction that is parallel to the road and opposite to that of the ego-vehicle. Consequently, the pedestrian on the left side does not show any clear intention of crossing the road, based on their position and trajectory. The ego-vehicle will yield to the pedestrian on the right side, while communicating its yielding intention only to the pedestrian on the right by means of its external HMI (eHMI). The pedestrian on the left side must not be addressed by means of the ego-vehicle eHMI. |
| **Graphical diagram** | |

| | |
|---|---|
| |  |
| **Sequence diagram** |  |
| **Relevance** | The intent of this experiment is to detect multiple pedestrians on different sides of the road and evaluate which pedestrian is relevant to the situation. By interacting with the correct pedestrian, the traffic flow can be optimized while misunderstandings and dangerous situations are avoided. Additionally, only the relevant pedestrian should be addressed, again, to avoid misunderstandings among all parties and also to avoid visual clutter. |
| **Addressed Interaction Actors** | Pedestrian (regular); ego-vehicle. |
| **Addressed user needs (D1.1)** | • Pedestrians must be robustly perceived by automated vehicles at all times.<br>• Use of appropriate and unequivocal vehicle signalling (as a means to acknowledge the presence of the pedestrian).<br>• Interactions with automated vehicles must lead to a smaller number of dangerous behaviours.<br>• Smooth and intuitive interactions with automated vehicles.<br>• Improved perception of comfort and enhanced feeling of respect when interacting with vehicles. |
| **Validation** | Simulator |

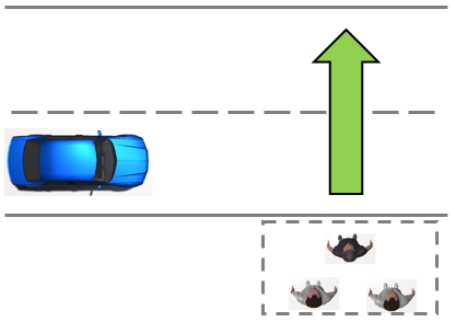
### 4.2.5 Experiment 5: Detection of relevant interaction partner on same roadside

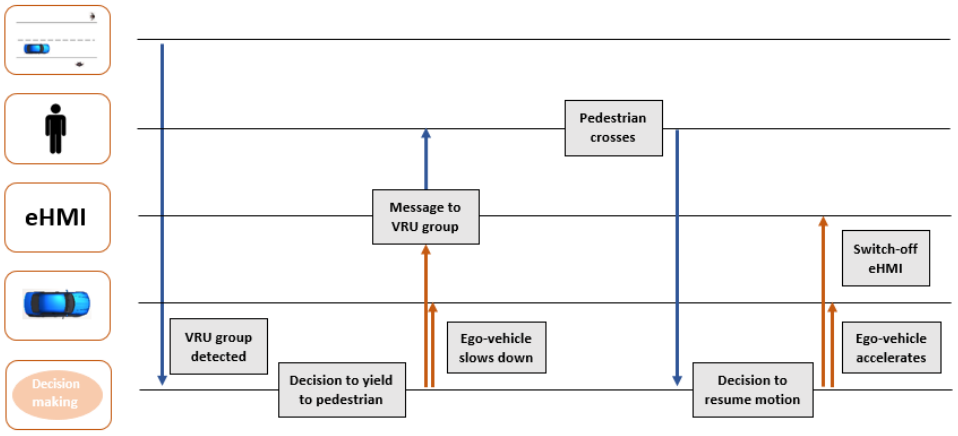
| Use Case | Use Case 2 |
|---|---|
| **Experiment** | #5. Detection of relevant interaction partner on same roadside. |
| **SAE Level** | 3 |
| **Environment** | Urban. |

| | |
|---|---|
| **Description** | A SAE Level-3 ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches two standing pedestrians, located by the road curb at the right-hand side. Both pedestrians are oriented towards the road. The two pedestrians are regular (not suffering any perceived impairment condition). The pedestrian standing further back is looking for eye contact with the driver of the ego-vehicle, indicating a clear intention to start crossing the road. The pedestrian in the front is not showing any crossing intention. The ego-vehicle will yield to the pedestrian trying to cross, while communicating its yielding intention only to that pedestrian by means of its external HMI (eHMI). The other pedestrian must not be addressed by means of the ego-vehicle eHMI. |
| **Graphical diagram** |  |
| **Sequence diagram** |  |
| **Relevance** | The intent of this experiment is to detect multiple pedestrians on different sides of the road and evaluate which pedestrian is relevant to the situation. By interacting with the correct pedestrian, the traffic flow can be optimized while misunderstandings and dangerous situations are avoided. Additionally, only the relevant pedestrian should be addressed, again, to avoid misunderstandings among all parties and also to avoid visual clutter. Compared to the previous experiment, this scenario shows an increased difficulty. More complex evaluations are required to determine which pedestrian should be addressed. The distance between the pedestrian also adds increased difficulty towards the eHMI design, which needs to be able to send the relevant information to the crossing pedestrian while not confusing the non-crossing pedestrian. |

| | |
|---|---|
| **Addressed Interaction Actors** | Pedestrian (regular); ego-vehicle |
| **Addressed user needs (D1.1)** | • Pedestrians must be robustly perceived by automated vehicles at all times.<br>• Use of appropriate and unequivocal vehicle signalling (as a means to acknowledge the presence of the pedestrian).<br>• Interactions with automated vehicles must lead to a smaller number of dangerous behaviours.<br>• Smooth and intuitive interactions with automated vehicles.<br>• Improved perception of comfort and enhanced feeling of respect when interacting with vehicles. |
| **Validation** | Simulator; proving ground TRL5. |

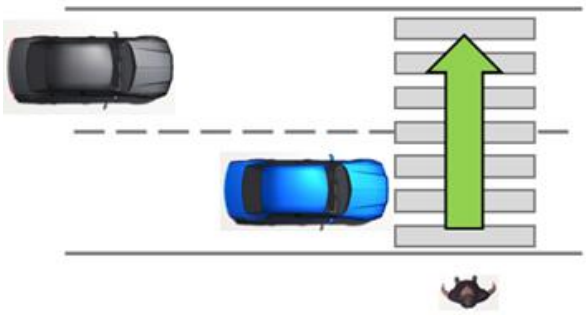
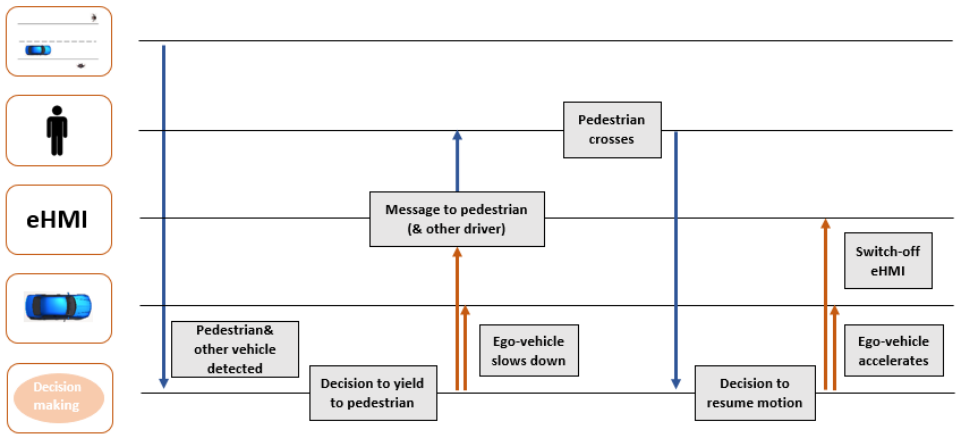
### 4.2.6 Experiment 6: VRU group interaction

| Use Case | Use Case 2 |
|---|---|
| **Experiment** | #6. VRU group interaction. |
| **SAE Level** | 3 |
| **Environment** | Urban. |
| **Description** | A SAE Level-3 ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches a group of three pedestrians, located by the road curb at the right-hand side. All pedestrians are oriented towards the road and are regular (not suffering any perceived impairment condition). At least one pedestrian is looking for eye contact with the driver of the ego-vehicle, indicating a clear intention to start crossing the road. The ego-vehicle will yield to the pedestrian group, while communicating its yielding intention to the pedestrian group by means of its external HMI (eHMI). |
| **Graphical diagram** |  |

| | |
|---|---|
| **Sequence diagram** |  |
| **Relevance** | By interaction with a pedestrian group in this experiment, it can be evaluated how to group the intentions of multiple individual pedestrians. Knowing if the intent of multiple pedestrians aligns and they can be treated as a group, can potentially influence the behaviour of the ego-vehicle and also avoid visual clutter and thus confusion and misunderstandings, thus increasing traffic flow and safety. |
| **Addressed Interaction Actors** | Pedestrian group (regular); ego-vehicle. |
| **Addressed user needs (D1.1)** | • Pedestrians must be robustly perceived by automated vehicles at all times.<br>• Use of appropriate and unequivocal vehicle signalling (as a means to acknowledge the presence of the pedestrian).<br>• Interactions with automated vehicles must lead to a smaller number of dangerous behaviours.<br>• Smooth and intuitive interactions with automated vehicles.<br>• Improved perception of comfort and enhanced feeling of respect when interacting with vehicles. |
| **Validation** | Simulator; proving ground TRL5. |

### 4.2.7 Experiment 7: VRU interaction with obstructed sight of approaching vehicle

| Use Case | Use Case 2 |
|---|---|
| **Experiment** | #7. VRU interaction with obstructed sight of approaching vehicle. |
| **SAE Level** | 3 |
| **Environment** | Urban, crossing. |
| **Description** | A SAE Level-3 ego-vehicle is driving along a two-lane one-way road in an urban environment, approaching a pedestrian crossing. The ego-vehicle is driving on the left lane while another vehicle is driving a little further back in the same direction. Both vehicles approach a standing pedestrian, located the right road curb. The pedestrian is regular (not suffering any perceived impairment condition). The pedestrian is looking for eye contact with the driver of the ego-vehicle and is oriented towards the road in a position that indicates a clear intention to start crossing the road. The ego-vehicle yields |

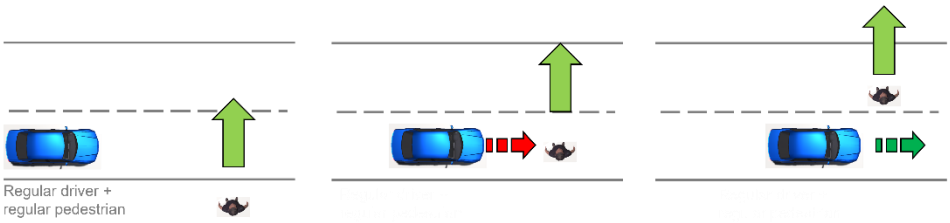
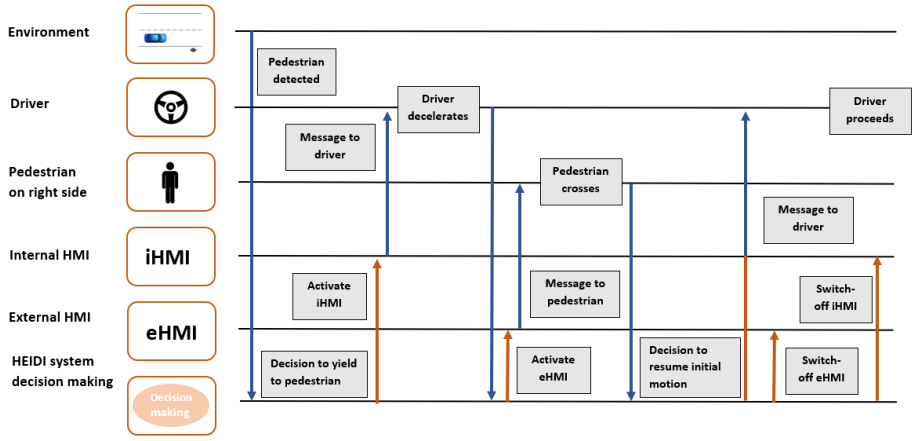
| | |
|---|---|
| | to the pedestrian. However, the line of sight between the pedestrian and the other vehicle is obstructed by the ego-vehicle. The ego-vehicle notifies the pedestrian of its yielding intention and additionally of the approaching other vehicle. Potentially, the other vehicle is also notified of the crossing pedestrian by the ego-vehicle. |
| **Graphical diagram** |  |
| **Sequence diagram** |  |
| **Relevance** | The addition of another driver allows for many additional scenarios. Here, the focus is on providing additional information about the environment which is inaccessible to other traffic participants. Like the obstruction of line of sight by the ego-vehicle. By providing information only accessible to the ego-vehicle, the safety can also be increased for other parties. |
| **Addressed Interaction Actors** | Pedestrian (regular); ego-vehicle; other drivers. |
| **Addressed user needs (D1.1)** | • Pedestrians must be robustly perceived by automated vehicles at all times.<br>• Use of appropriate and unequivocal vehicle signalling (as a means to acknowledge the presence of the pedestrian).<br>• Interactions with automated vehicles must lead to a smaller number of dangerous behaviours.<br>• Smooth and intuitive interactions with automated vehicles.<br>• Improved perception of comfort and enhanced feeling of respect when interacting with vehicles. |
| **Validation** | Simulator. |

## 4.3 Use Case 3

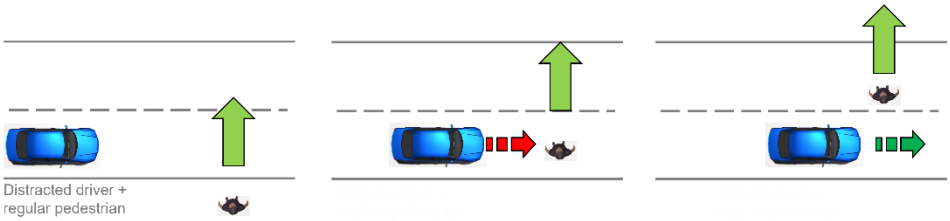
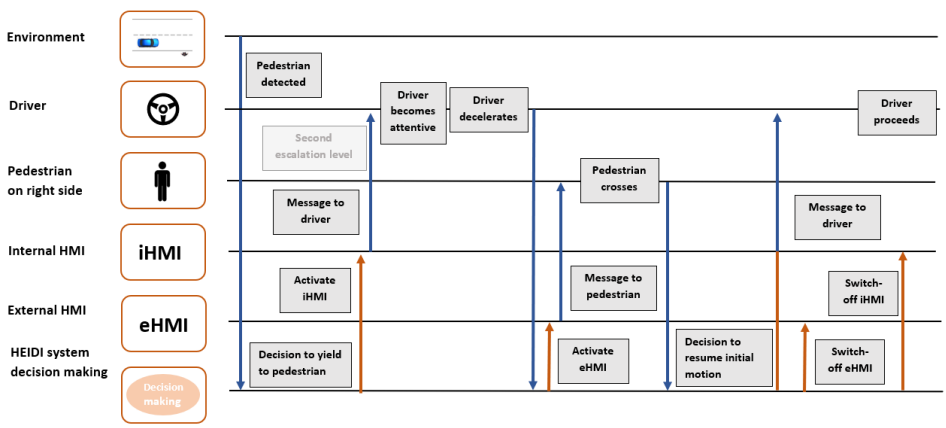
Using use case 3, we will test and validate the fluid cHMI. The main goal of this use case is to demonstrate that we can generally facilitate mutual cooperation and resolve ambiguous traffic situations. In separate experiments, we will show that we are able to allow for cooperation between different road users with varying characteristics by implementing a cHMI with several urgency levels in case one or more of the interaction partners do not adhere to the communicated optimal behaviour in the first place. We will also demonstrate that our system is able to safely resolve situations, in which one or more interaction partners completely disregard the communicated behaviour, by tracking the resolution and proposing alternative behaviour options if necessary. As a general outline for the conducted experiments that will be explained in the following, we do not assume risky and hazardous pedestrian behaviour which would require an emergency fallback reaction of the driver although we assume that such a fallback system would be available if necessary. Moreover, the graphical and sequential diagrams only represent schematic drawings of how the situation could potentially evolve and how the cHMI could communicate to result in the suggested outcome.

### 4.3.1 Experiment 1: Interaction between a regular driver and a regular pedestrian at an unsignalized crossing

| Use Case | Use Case 3 |
|---|---|
| **Experiment** | #1, Interaction between a regular driver and a regular pedestrian at an unsignalized crossing. |
| **SAE Level** | Level 1/2. |
| **Environment** | Urban. |
| **Description** | A regular driver (i.e., no old driver or any inattentiveness detected) in a SAE Level-1/2 (fully responsible) ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches a standing pedestrian, located by the road curb on the right-hand side. The pedestrian is regular (i.e., no inattentiveness or any impairment condition detected) and is located in an area of the road where there is no signalized or zebra crossing. The pedestrian is looking for eye contact with the driver of the ego-vehicle and is oriented towards the road in a position that indicates a clear intention to cross the road. The outcome of the situation is very ambiguous such that neither of the involved entities can clearly predict whether the respective interaction partner will let one pass first. In order to facilitate cooperation and give the pedestrian the opportunity to cross, the ego-vehicle should yield to the pedestrian. This recommended behaviour will be communicated to the driver via the iHMI, while communicating the yielding intention to the pedestrian by means of the eHMI, thus granting the right of way to the pedestrian. All parties adhere to the recommended behaviour. |
| **Graphical diagram** | |

| | |
|---|---|
| |  |
| **Sequence diagram** |  |
| **Relevance** | This experiment is meant to assess the cooperation between a regular driver and a regular pedestrian located at a non-signalized crossing area. This interaction is intended to resolve ambiguous traffic situations and to enhance road safety while increasing the mutual understanding between pedestrians and drivers and reducing the number of dangerous pedestrian behaviours. The recommended behaviour must mitigate the collision risk, increase mutual intent and behaviour understanding and lead to a more fluent interaction with pedestrians showing the intention of crossing the road, even if they are located at unsignalized crossing areas. |
| **Addressed Interaction Actors** | Regular driver, regular pedestrian. |
| **Addressed user needs (D1.1)** | • Fully responsible ego-drivers need unconfusing, comprehensible and concise communication.<br>• Fully responsible ego-drivers need to be able to understand the situation.<br>• Fully responsible ego-drivers must be able to predict future situation unfolding and react accordingly.<br>• Pedestrians need to be robustly perceived by vehicles at all times and in all directions, including under adverse weather conditions and at night-time.<br>• Pedestrians need to feel respected and acknowledged by vehicles.<br>• Pedestrians need unconfusing, comprehensible and concise communication.<br>• Pedestrians need to be able to understand the situation. |
| **Validation** | Simulator, proving ground TRL6 (pre-validation for live demo). |

### 4.3.2 Experiment 2: Interaction between a distracted driver and a regular pedestrian at an unsignalized crossing

| Use Case | Use Case 3 |
|---|---|
| **Experiment** | #2, Interaction between a distracted driver and a regular pedestrian at an unsignalized crossing. |
| **SAE Level** | Level 1/2. |
| **Environment** | Urban. |
| **Description** | A distracted driver in a SAE Level-1/2 (fully responsible) ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches a standing pedestrian, located by the road curb on the right-hand side. The pedestrian is regular (i.e., no inattentiveness or any impairment condition detected) and is located in an area of the road where there is no signalized or zebra crossing. The pedestrian is looking for eye contact with the driver of the ego-vehicle and is oriented towards the road in a position that indicates a clear intention to cross the road. The driver does not realize the pedestrian and the pedestrian is not sure whether the driver will let him/her pass first. In order to facilitate cooperation and give the pedestrian the opportunity to cross, the ego-vehicle should yield to the pedestrian. This recommended behaviour will be communicated to the driver via the iHMI. However, the distraction of the driver requires an adequate communication on a higher escalation level. The yielding intention of the driver will be communicated to the pedestrian by means of the eHMI, thus granting the right of way to the pedestrian. All parties adhere to the recommended behaviour. |
| **Graphical diagram** |  |
| **Sequence diagram** |  |
| **Relevance** | This experiment is meant to assess the cooperation between a distracted driver and a regular pedestrian located at a non-signalized crossing area. |

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| | As the pedestrian cannot be sure whether the driver has seen him/her, the cooperative system needs to assure the attentiveness of the driver. The communication must happen early enough and in a fashion such that it allocates the driver's attention where it is necessary while taking the limited cognitive resources of the driver into account. The recommended behaviour must mitigate the collision risk, increase mutual intent and behaviour understanding and lead to a more fluent interaction with pedestrians showing the intention of crossing the road, even if they are located at unsignalized crossing areas. |
| **Addressed Interaction Actors** | Distracted driver, regular pedestrian. |
| **Addressed user needs (D1.1)** | • Distracted ego-drivers need unconfusing, comprehensible and concise communication.<br>• Distracted ego-drivers need to perceive their environment and allocate their attention where it is required.<br>• Distracted ego-drivers need to be able to filter relevant information and understand the situation early enough.<br>• Pedestrians need to be robustly perceived by vehicles at all times and in all directions, including under adverse weather conditions and at night-time.<br>• Pedestrians need to feel respected and acknowledged by vehicles.<br>• Pedestrians need unconfusing, comprehensible and concise communication.<br>• Pedestrians need to be able to understand the situation. |
| **Validation** | Simulator, proving ground TRL6 (pre-validation for live demo). |

### 4.3.3 Experiment 3: Interaction between a regular driver and a group of distracted pedestrians at an unsignalized crossing

| Use Case | Use Case 3 |
|---|---|
| **Experiment** | #3, Interaction between a regular driver and a group of distracted pedestrians at an unsignalized crossing. |
| **SAE Level** | Level 1/2. |
| **Environment** | Urban. |
| **Description** | A regular driver (i.e., no old driver or any inattentiveness detected) in a SAE Level-1/2 (fully responsible) ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches a group of pedestrians, located by the road curb on the right-hand side in an area where there is no signalized or zebra crossing. The position of the pedestrians and their orientation indicate the intention to cross the road. The pedestrians are distracted and do not realize the approaching vehicle hence the driver is unsure whether the pedestrians will cross first. In order to facilitate cooperation and give the pedestrians the opportunity to cross, |

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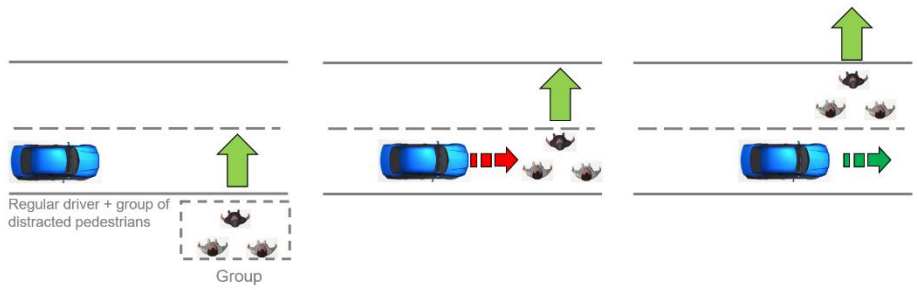
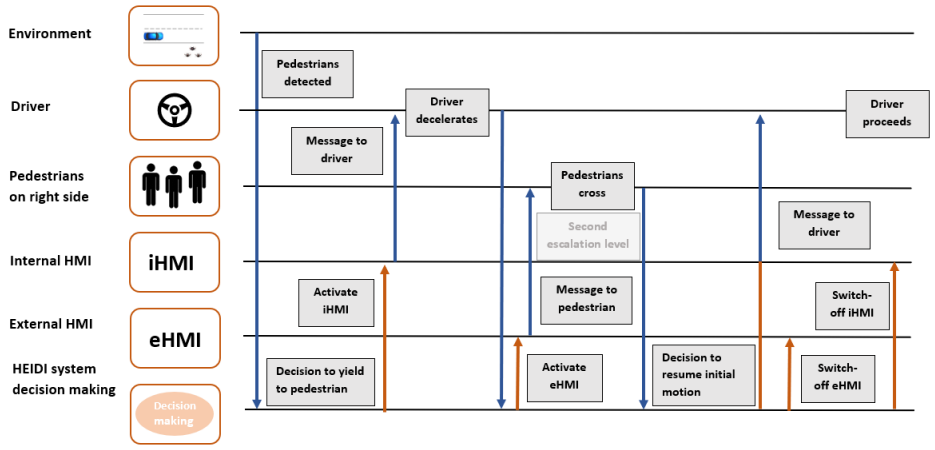
| | the ego-vehicle should yield to the pedestrians. This recommended behaviour will be communicated to the driver via the iHMI, while communicating the yielding intention to the pedestrians by means of the eHMI, thus granting the right of way to the pedestrians. All parties adhere to the recommended behaviour. |
| **Graphical diagram** |  |
| **Sequence diagram** |  |
| **Relevance** | This experiment is meant to assess the cooperation between a regular driver and distracted pedestrians located at a non-signalized crossing area. This interaction is intended to account for both the behaviour of groups of pedestrians as well as the characteristics of distracted pedestrians. As the driver cannot be sure whether the pedestrians have seen him/her, the cooperative system needs to assure the awareness of the driver. On the other hand, the communication must happen early enough and in a fashion such that it allocates the pedestrians' attention where it is necessary while taking the behaviour of groups and the characteristics of distracted pedestrians into account. |
| **Addressed Interaction Actors** | Regular driver, group of distracted pedestrians. |
| **Addressed user needs (D1.1)** | • Fully responsible ego-drivers need unconfusing, comprehensible and concise communication.<br>• Fully responsible ego-drivers need to be able to understand the situation.<br>• Fully responsible ego-drivers must be noticed by other road users.<br>• Fully responsible ego-drivers must be able to predict future situation unfolding and react accordingly. |

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| | • Pedestrians need to be robustly perceived by vehicles at all times and in all directions, including under adverse weather conditions and at night-time.<br>• Pedestrians need to feel respected and acknowledged by vehicles.<br>• Pedestrians need unconfusing, comprehensible and concise communication.<br>• Pedestrians need to be able to understand the situation.<br>• A group of pedestrians must be accordingly addressed, and a potential group leader needs to be identified. |
| **Validation** | Simulator, proving ground TRL6 (pre-validation for live demo). |

### 4.3.4 Experiment 4: Interaction between a distracted driver and a regular pedestrian at an unsignalized crossing, with not-adhering driver

| Use Case | Use Case 3 |
|---|---|
| **Experiment** | #4, Interaction between a distracted driver and a regular pedestrian at an unsignalized crossing, with not-adhering driver. |
| **SAE Level** | Level 1/2. |
| **Environment** | Urban. |
| **Description** | A distracted driver in a SAE Level-1/2 (fully responsible) ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches a standing pedestrian, located by the road curb on the right-hand side. The pedestrian is regular (i.e., no inattentiveness or any impairment condition detected) and is located in an area of the road where there is no signalized or zebra crossing. The pedestrian is looking for eye contact with the driver of the ego-vehicle and is oriented towards the road in a position that indicates a clear intention to cross the road. The situation is very ambiguous such that neither of the involved entities can clearly predict whether the respective interaction partner will let one pass first. In order to facilitate cooperation and give the pedestrian the opportunity to cross, the ego-vehicle should yield to the pedestrian. This recommended behaviour will be communicated to the driver via the iHMI, while communicating the yielding intention to the pedestrian by means of the eHMI, thus granting the right of way to the pedestrian. However, due to the driver's distraction the driver changes his/her decision to yield to the pedestrian and does not adhere to the initially communicated optimal behaviour any longer such that the system needs to be able to track the behaviour and recommend an alternative safe option. The new behaviour will be communicated to both interaction partners. |
| **Graphical diagram** | |

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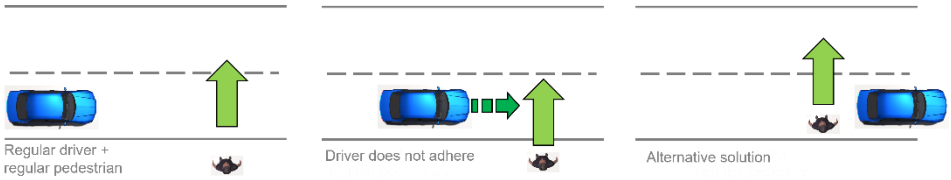
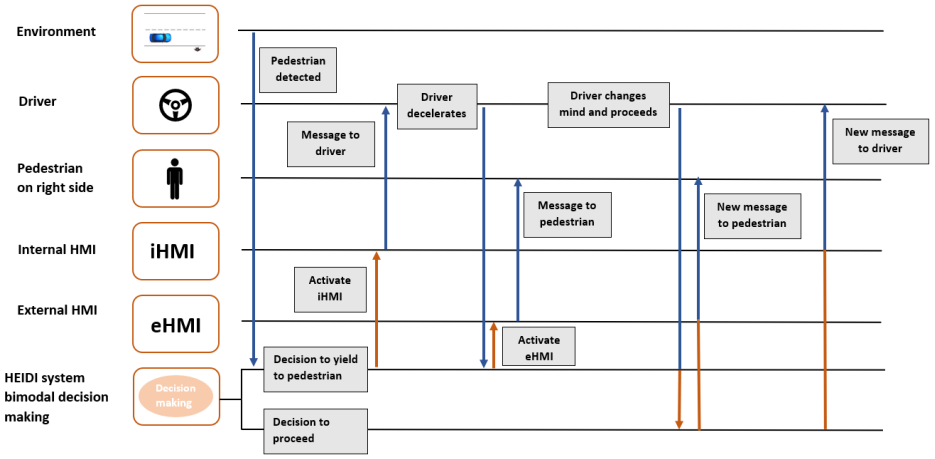
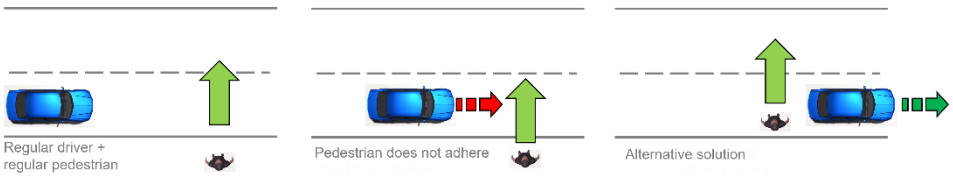
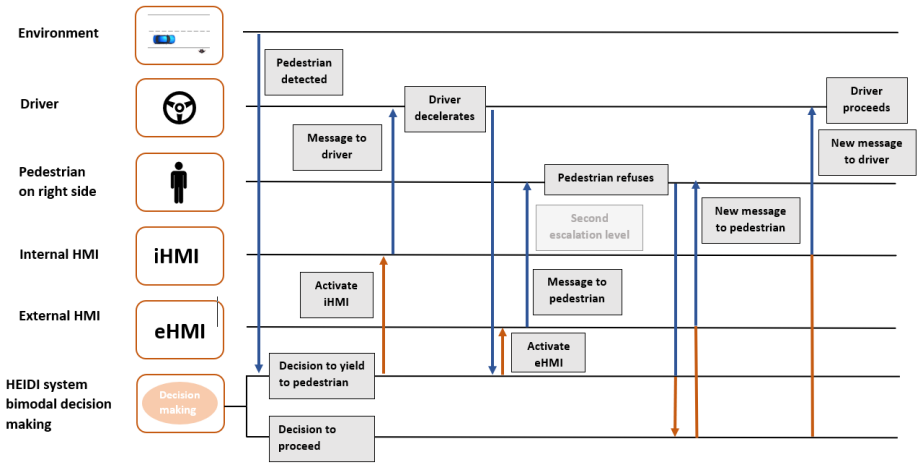
| |  |
| **Sequence diagram** |  |
| **Relevance** | This experiment is meant to assess the interaction between a distracted driver and a regular pedestrian when the driver does not adhere to the initially communicated behaviour. This interaction is intended to show that the system is capable of tracking the driver behaviour and communicate alternative behaviour recommendations yet guarantee safety for all interaction partners. |
| **Addressed Interaction Actors** | Distracted driver, regular pedestrian. |
| **Addressed user needs (D1.1)** | • Distracted ego-drivers need unconfusing, comprehensible and concise communication.<br>• Distracted ego-drivers need to perceive their environment and allocate their attention where it is required.<br>• Distracted ego-drivers need to be able to filter relevant information and understand the situation early enough.<br>• Pedestrians need to be robustly perceived by vehicles at all times and in all directions, including under adverse weather conditions and at night-time.<br>• Pedestrians need to feel respected and acknowledged by vehicles.<br>• Pedestrians need unconfusing, comprehensible and concise communication.<br>• Pedestrians need to be able to understand the situation. |
| **Validation** | Simulator. |

### 4.3.5 Experiment 5: Interaction between a regular driver and a distracted pedestrian at an unsignalized crossing, with not-adhering pedestrian

| Use Case | Use Case 3 |
|---|---|
| **Experiment** | #5, Interaction between a regular driver and a distracted pedestrian at an unsignalized crossing, with not-adhering pedestrian. |
| **SAE Level** | Level 1/2. |
| **Environment** | Urban. |
| **Description** | A regular driver (i.e., no old driver or any inattentiveness detected) in a SAE Level-1/2 (fully responsible) ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches a standing pedestrian, located by the road curb on the right-hand side. The pedestrian's position and orientation indicate the intention to cross the road. The pedestrian is distracted, and the driver is unsure whether the pedestrian will cross first. In order to facilitate cooperation and give the pedestrian the opportunity to cross, the ego-vehicle should yield to the pedestrian. This recommended behaviour will be communicated to the driver via the iHMI, while communicating the yielding intention to the pedestrian by means of the eHMI, thus granting the right of way to the pedestrian. However, due to the pedestrian's distraction, he/she does not accept this offer and does not adhere to the initially communicated optimal behaviour such that the system needs to be able to track the behaviour and recommend an alternative safe option. The new behaviour will be communicated to both interaction partners. |
| **Graphical diagram** |  |
| **Sequence diagram** |  |
| **Relevance** | This experiment is meant to assess the interaction between a regular driver and a regular pedestrian when the pedestrian does not adhere to |

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| | the initially communicated behaviour. This interaction is intended to show that the system is capable of tracking the pedestrian behaviour and communicate alternative behaviour recommendations yet guarantee safety for all interaction partners. At the same time, a freezing robot situation will be successfully avoided. |
| **Addressed Interaction Actors** | Regular driver, distracted pedestrian. |
| **Addressed user needs (D1.1)** | • Fully responsible ego-drivers need unconfusing, comprehensible and concise communication.<br>• Fully responsible ego-drivers need to be able to understand the situation.<br>• Fully responsible ego-drivers must be noticed by other road users.<br>• Fully responsible ego-drivers must be able to predict future situation unfolding and react accordingly.<br>• Pedestrians need to be robustly perceived by vehicles at all times and in all directions, including under adverse weather conditions and at night-time.<br>• Pedestrians need to feel respected and acknowledged by vehicles.<br>• Pedestrians need unconfusing, comprehensible and concise communication.<br>• Pedestrians need to be able to understand the situation. |
| **Validation** | Simulator. |

### 4.3.6 Experiment 6: Interaction between a distracted driver and a group of distracted pedestrians at an unsignalized crossing

| Use Case | Use Case 3 |
|---|---|
| **Experiment** | #6, Interaction between a distracted driver and a group of distracted pedestrians at an unsignalized crossing, with no one adhering to the initial behaviour recommendation. |
| **SAE Level** | Level 1/2. |
| **Environment** | Urban. |
| **Description** | A distracted driver in a SAE Level-1/2 (fully responsible) ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches a group of pedestrians, located by the road curb on the right-hand side in an area where there is no signalized or zebra crossing. The position of the pedestrians and their orientation indicate the intention to cross the road. In order to facilitate cooperation and give the pedestrians the opportunity to cross, the ego-vehicle should yield to the pedestrians. This recommended behaviour will be communicated to the driver via the iHMI, while communicating the yielding intention to the pedestrians by means of the eHMI, thus granting the right of way to the pedestrians. However, due to their distraction, no one adheres to the |

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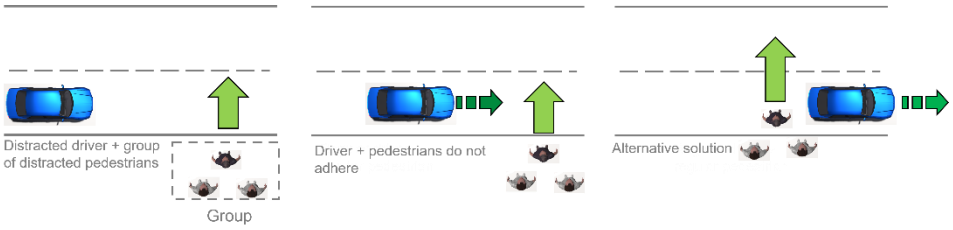
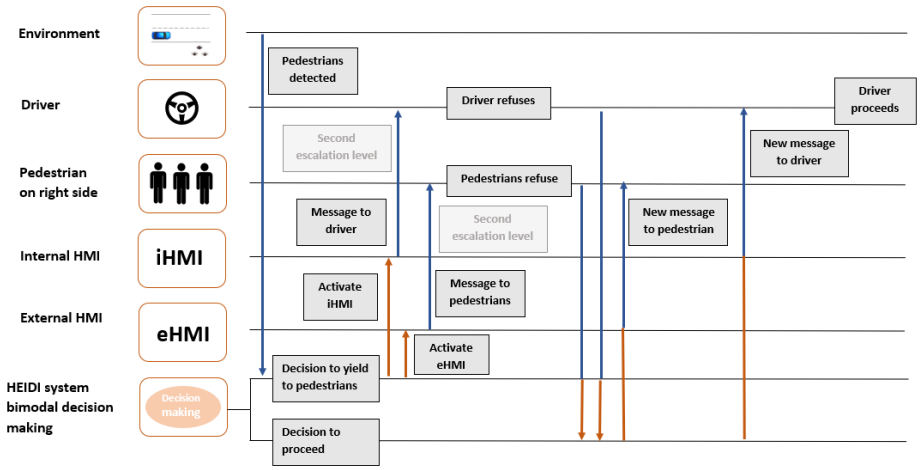
| | initially communicated optimal behaviour such that the system needs to be able to track the behaviour and recommend an alternative safe option. The new behaviour will be communicated to both interaction partners. |
| **Graphical diagram** |  |
| **Sequence diagram** |  |
| **Relevance** | This experiment is meant to assess the interaction between a distracted driver and a group of distracted pedestrians when no one adheres to the initially communicated behaviour. This interaction is intended to show that the system is capable of tracking everyone's behaviour and communicate alternative behaviour recommendations according to the evolution of the situation yet guarantee safety for all interaction partners. At the same time, a freezing robot situation will be successfully avoided. |
| **Addressed Interaction Actors** | Distracted driver, group of distracted pedestrians. |
| **Addressed user needs (D1.1)** | • Distracted ego-drivers need unconfusing, comprehensible and concise communication.<br>• Distracted ego-drivers need to perceive their environment and allocate their attention where it is required.<br>• Distracted ego-drivers need to be able to filter relevant information and understand the situation early enough.<br>• Distracted ego-drivers must be noticed by other road users.<br>• Pedestrians need to be robustly perceived by vehicles at all times and in all directions, including under adverse weather conditions and at night-time.<br>• Pedestrians need to feel respected and acknowledged by vehicles.<br>• Pedestrians need unconfusing, comprehensible and concise communication. |

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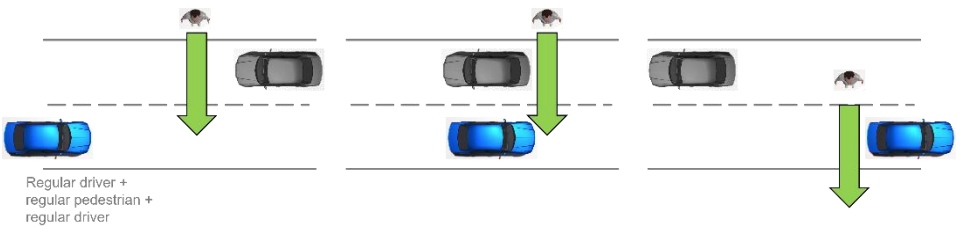
|---|---|
| | • Pedestrians need to be able to understand the situation.<br>• A group of pedestrians must be accordingly addressed, and a potential group leader needs to be identified. |
| **Validation** | Simulator. |

### 4.3.7 Experiment 7: Interaction between a regular driver, a regular pedestrian at another coming vehicle with a regular driver at an unsignalized crossing

| Use Case | Use Case 3 |
|---|---|
| **Experiment** | #7, Interaction between a regular driver, a regular pedestrian at another oncoming vehicle with a regular driver at an unsignalized crossing. |
| **SAE Level** | Level 1/2. |
| **Environment** | Urban. |
| **Description** | A regular driver (i.e., no old driver or any inattentiveness detected) in a SAE Level-1/2 (fully responsible) ego-vehicle is driving along a two-way road in an urban environment, with one lane per driving direction, without any signalized pedestrian crossing nearby. The ego-vehicle approaches a standing pedestrian, located by the road curb on the left-hand side. The pedestrian is regular (i.e., no inattentiveness or any impairment condition detected) and is located in an area of the road where there is no signalized or zebra crossing. The pedestrian's position and its orientation indicate a clear intention to cross the road. Additionally, another oncoming vehicle with a regular driver is approaching the situation. Without the oncoming vehicle, this experiment would be similar to Experiment#1 and the cHMI would facilitate the cooperation between the ego-driver and the pedestrian in order to let the pedestrian cross the road. However, the oncoming vehicle changes the context of the cooperation and thus changes the optimal behaviour and the communication. The recommended behaviour will be communicated to the driver via the iHMI, while communicating to the pedestrian and the external driver by means of the eHMI. All parties adhere to the recommended behaviour. |
| **Graphical diagram** |  |

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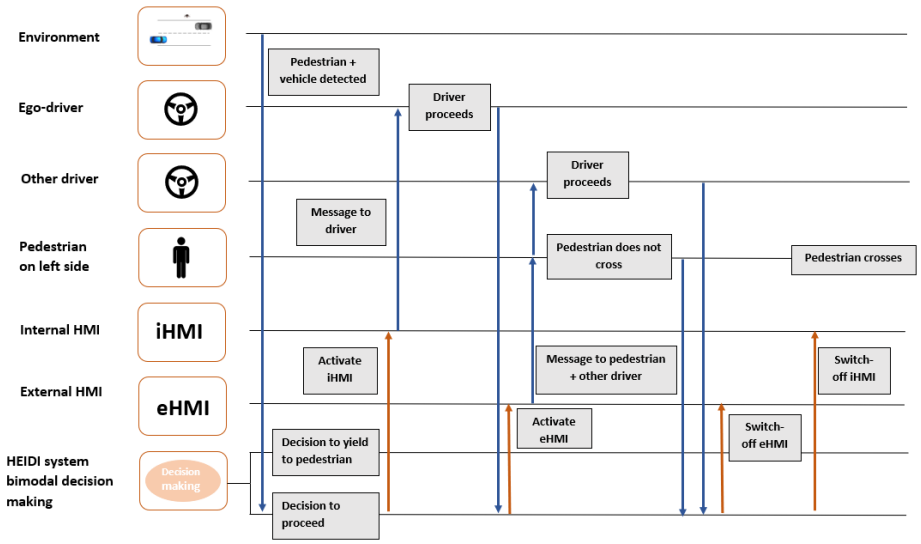
|---|---|
| **Sequence diagram** |  |
| **Relevance** | This experiment is meant to assess the interaction between three interacting parties. This interaction is intended to show that the system is capable of taking the interests of multiple interaction partners into account and thus find an optimal joint behaviour for them. |
| **Addressed Interaction Actors** | Regular ego-driver, regular pedestrian, regular other drivers. |
| **Addressed user needs (D1.1)** | • Fully responsible drivers need unconfusing, comprehensible and concise communication.<br>• Fully responsible drivers need to be able to understand the situation.<br>• Fully responsible drivers must be able to predict future situation unfolding and react accordingly.<br>• External drivers need to be informed about the state of a potentially automated vehicle.<br>• External drivers need to be informed about the intended behaviour, the next manoeuvres and the cooperation capabilities.<br>• Pedestrians need to be robustly perceived by vehicles at all times and in all directions, including under adverse weather conditions and at night-time.<br>• Pedestrians need to feel respected and acknowledged by vehicles.<br>• Pedestrians need unconfusing, comprehensible and concise communication.<br>• Pedestrians need to be able to understand the situation. |
| **Validation** | Simulator. |

# 5. Conclusion

This document has described the different use cases to be developed and tested in the framework of the HEIDI project. For each use case, a number of experiments have been designed and described in detail, including textural and graphical descriptions of the experiment, relevance, sequence diagram, involved actors, SAE level, and addressed user needs. All the experiments will be considered in simulators, and a few of them will also be demonstrated on a real vehicle on a test track. Appropriate onboard sensors, HMI systems, and perception functionalities will be necessary for demonstrations on a real vehicle. The main goal is to assess the advanced features of the proposed iHMI (UC1), eHMI (UC2), and cHMI (UC3), respectively, in the context of complex interactions with the ego-driver, pedestrians, and external drivers in different conditions (regular, distracted, impaired, older). Use cases propose different experiments in an incremental way, from UC1 (iHMI), through UC2 (eHMI), until UC3 (cHMI). A central objective of the proposed use cases is to analyse HEIDI's capacity to address different road users in the appropriate manner (appropriate interaction with regular, distracted, impaired, and older road user), to address the relevant road user (in a context where only one road user is relevant regarding potential interactions with the ego-vehicle while all other road users do not intervene in the interaction), and to properly address a group of users (e.g., groups of pedestrians). The proposed use cases provide the guidelines for the experiments that will be conducted in the framework of work packages 2 – 5. Conclusions on those results will be documented in future deliverables.

# 6. Abbreviations

| Term | Definition |
|---|---|
| D | Deliverable |
| HEIDI | Holistic and adaptivE Interface Design for human-technology Interactions |
| HMI | Human-Machine Interface |
| cHMI | Cooperative HMI |
| iHMI | Internal HMI |
| eHMI | External HMI |
| PU | Public |
| R | Document, Report |
| SAE | Society of Automotive Engineers |
| TRL | Technology Readiness Level |
| UC | Use Case |
| WP | Work Package |
| VRU | Vulnerable Road Users |

# 7. References

[1] HEIDI Project. Deliverable D1.1 – User Needs.

[2] Society of Automotive Engineers – Levels of Automation. https://www.sae.org.