eHMI of Autonomous Vehicles:
Should autonomous vehicles communicate with pedestrians, and if so, how?

Stefanie Faas, PIONEER/NG NeXt
To Find a Common Language: external Human Machine Interface (eHMI)

- When deploying autonomous vehicles it is a set goal that all road users feel safe.
- Nowadays, most pedestrians are seeking eye-contact with the driver when crossing a street.
- In the presence of automated vehicles, communication will no longer be possible between two humans (i.e. driver – pedestrian).
- An external Human Machine Interface (eHMI) provides an interface between autonomous vehicles and pedestrians.
Autonomous Vehicle to Pedestrian Communication

AVP: Focus Groups
MB Museum, December 2017

Wizard-of-Oz Field Study
Sindelfingen, October 2017

Wizard-of-Oz Field Study
Immendingen, September 2018
Autonomous Vehicle to Pedestrian Communication

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Immendingen, September 2018
## Automated Valet Parking (AVP): Focus Groups

| **Research questions** | Should the autonomous driving mode be displayed externally?  
| | Location of eHMI: Front or 360° display? |
| **Method** | Think Aloud Technique  
| | Urban Scenario: Parking Garage  
| | Role: Pedestrian |
| **Sample** | 18 external participants (44% ♀, 56% ♂ / □ 45 years)  
| | Three groups with six participants each (16-35 years, 36-55 years, 56-70 years) |
| **Vehicle** | E-Class |
| **Survey Period** | 12/05/2017 |
Automated Valet Parking (AVP): Focus Groups

AVP is a joint pilot project of Mercedes-Benz and Bosch in Stuttgart.

We gathered focus groups on how pedestrians feel about the Automated Valet Parking system and especially the need of an eHMI.
Pedestrians Feel a Little Uncomfortable When Seeing a Driverless Vehicle

Pedestrians need to get used to autonomous driving.

- „Bizarre because nobody is sitting behind the wheel.“
- „Unusual feeling to see a car driving without a driver.“
- „The car doesn’t move naturally, much more evenly.“

Most pedestrians would like to see an indication that the vehicle is driving autonomously.

- „When I see a vehicle without any people sitting inside I want to know whether the vehicle might move eventually.“
- „When a vehicle is moving I am seeking eye contact with the driver. But with autonomous vehicles I don’t have anybody to communicate with anymore. An indication is important to me so I know there is no point in seeking the driver“.
Pedestrians Prefer 360° View for Autonomous Vehicles

Participants replied:

94% would like to see an indication that the ADS is activated*

100% prefer a 360° view**

* As pedestrian, would you like to see an indicator for autonomous vehicles?
** Assuming autonomous vehicles have an indicator, would you prefer a 360° view or a display at the front of the vehicle?
Autonomous Vehicle to Pedestrian Communication

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# Testing and Technology Center Sindelfingen: Wizard-of-Oz Field Study

| **Research questions** | Should the autonomous driving mode be displayed externally?  
| | Should autonomous vehicles signal their intention?  
| | Location of eHMI: Front or 360° display?  
| | Colour of eHMI: Turquoise or yellow?  

| **Method** | Field Study  
| | Urban Scenario: Zebra-Crossing  
| | Role: Pedestrian  

| **Sample** | 65 external participants (46% ♀, 54% ♂ // Ø 43 years)  

| **Vehicle** | E-Class  

| **Survey Period** | 09/25/2017 to 10/06/2017  

We gathered a field experiment on whether an eHMI compensates unavailable driver-centric cues.

The AV approaches a pedestrian at a zebra crossing and waits for the pedestrian to cross the road.
Two Test Vehicles

Left-hand drive
tinted windshield

Right-hand drive
transparent windshield
Right-Hand Drive: Wizard-of-Oz
Driver-Centric Cues: Three Test-Conditions

**Eye Contact**
The driver makes eye contact. Hands are not on the steering wheel.

**Reading Newspaper**
The driver is distracted and does not represent the actions of the vehicle.

**Tinted Windshield**
No driver-centric cues available. Unclear whether there is a driver or not.
An eHMI Helps Pedestrians to Interpret a Driverless Vehicle as Being no Threat

Without an eHMI, pedestrians take driver-centric cues into account. Compared to a driver making eye contact, pedestrians felt less safe when the driver was reading a newspaper or being invisible.

With an eHMI, pedestrians do not take driver-centric cues into account. Pedestrians felt equally safe regardless of the actions of the driver.
Pedestrians Prefer 360° View and Turquoise Light for Autonomous Vehicles

Participants replied:

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>81%</td>
<td>would like to see an indication that the ADS is activated*</td>
</tr>
<tr>
<td>79%</td>
<td>prefer a 360° view**</td>
</tr>
<tr>
<td>92%</td>
<td>prefer turquoise over yellow as ADS lighting colour***</td>
</tr>
</tbody>
</table>

* As pedestrian, would you like to see an indicator for autonomous vehicles?
** Assuming autonomous vehicles have an indicator, would you prefer a 360° view or a display at the front of the vehicle?
*** Assuming autonomous vehicles have a specified lighting colour, do you prefer turquoise or yellow as lighting colour for autonomous vehicles?
Pedestrians Would Like to See an Indication that the Autonomous Driving System is Activated

81% pro Status Lamp

81% pro Status Lamp

19% against Status Lamp

Gives me a sense of safety. With an indicator for autonomous vehicles I can assess the situation in a better way.

#Safety

The indicator confirms that the autonomic system is paying attention. Then I can be sure, the system is on.

#Awareness

One is less dependent of what happens in the vehicle. If the driver is distracted, the indicator provides feedback and security.

#No driver

Because I don’t trust the system yet..

#Raising trust

Especially for the introduction phase of autonomous vehicles. So that you can somehow recognize and identify autonomous vehicles.

#Introduction

If the system works, you don’t need an indicator. What should be the benefit?

#No benefit

Because pedestrians are overwhelmed with information. That wouldn’t go well. Pedestrians must always be careful, you can’t just walk across the street.

#Distraction

Assuming you are a pedestrian, would you like to see an indicator for autonomous vehicles? Why? (N=62)
Reasons why Pedestrians Prefer a 360° View

#Visibility
“Because you don’t always encounter the car from the frontal perspective” [Examples stated:]

#Perceptibility
“I think the 360° view is simply more obvious, at first glance. A single point of light can be easily overlooked.”

#Safety
“The 360° view is more reassuring as you are able to tell from every point of view whether the vehicle is autonomous.”

* Assuming you are a pedestrian, would you prefer a 360° view or a display at the front of the vehicle? Why a 360 ° view? (N=51)

* What do you associate with the colour turquoise shown? What do you associate with the colour yellow shown? (N=65)
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## Testing and Technology Center Sindelfingen: Wizard-of-Oz Field Study

| Research questions | Should the autonomous driving mode be displayed externally?  
|                   | Should autonomous vehicles signal their intention?  
|                   | Should autonomous vehicles signal their perception?  
|                   | Colour of eHMI: Turquoise or white?  
| Method            | Field Study  
|                   | Urban Scenarios: Street-Crossing, Parking Space  
|                   | Role: Pedestrian  
| Sample            | 60 external participants (47% ♂, 53% ♀ // Ø 43 years)  
| Vehicle           | E-Class  
| Survey Period     | 09/10/2018 to 09/21/2018  

At the new Testing and Technology Center Immendingen we are able to run field experiments under realistic conditions.

We gathered a field study on how autonomous vehicles should communicate with pedestrians.
Street Crossing Scenario

The AV approaches a pedestrian at a crossing without traffic lights and waits for the pedestrian to cross the road.
Parking Space Scenario

At a parking space, the AV is blocked by a pedestrian. The AV wants to notify the pedestrian that it wants to go.
Wizard-of-Oz: Seat Costume
Pedestrians Prefer Turquoise Light for Autonomous Vehicles

<table>
<thead>
<tr>
<th>Participants replied:</th>
<th>85%</th>
<th>93%</th>
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<td>would like to see an indication that the ADS is activated</td>
<td></td>
<td>prefer turquoise over white as ADS lighting colour</td>
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* As pedestrian, would you like to see an indicator for autonomous vehicles?
*** Assuming autonomous vehicles have a specified lighting colour, do you prefer turquoise or white as lighting colour for autonomous vehicles?
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Pedestrians Prefer 360° View and Turquoise Light for Autonomous Vehicles

Participants replied:

94%¹ / 81%² / 85%³ would like to see an indication that the ADS is activated*

100%¹ / 79%² prefer a 360° view**

92%² / 93%³ prefer turquoise over yellow resp. white as ADS lighting colour***

¹ Automated Valet Parking: Focus groups (N=18)
² Testing and Technology Center Sindelfingen: Field study (N=65)
³ Testing and Technology Center Immendingen: Field study (N=60)

* As pedestrian, would you like to see an indicator for autonomous vehicles?
** Assuming autonomous vehicles have an indicator, would you prefer a 360° view or a display at the front of the vehicle?
*** Assuming autonomous vehicles have a specified lighting colour, do you prefer turquoise or yellow resp. white as lighting colour for autonomous vehicles?
Key Findings

- Pedestrians feel a little uncomfortable when seeing a driverless vehicle
- An eHMI helps pedestrians to interpret a driverless vehicle as being no threat
- Pedestrians prefer a 360° eHMI
- Pedestrians prefer turquoise as autonomous vehicle lighting colour.