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1 Title: **Designing the interaction of automated vehicles with other traffic participants: Design**
2 **considerations based on human needs and expectations**

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13 **Abstract**

14 Automated vehicles (AV) are expected to be integrated into mixed traffic environments in the near future. As
15 human road users have established elaborated interaction strategies to coordinate their actions among each other,
16 one challenge that Human Factors experts and vehicle designers are facing today is how to design AVs in a way
17 that they can safely and intuitively interact with other traffic participants. This paper presents design
18 considerations that are intended to support AV designers in reducing the complexity of the design space. The
19 design considerations are based on a literature review of common human-human interaction strategies. Four
20 categories of information are derived for the design considerations: 1) information about vehicle driving mode;
21 2) information about AVs' manoeuvres; 3) information about AVs' perceptions of the environment; and 4)
22 information about AVs' cooperation capabilities. In this paper, we apply the four categories to analyse existing
23 research studies of traffic participants' needs during interactions with AVs, and results of the CityMobil2 project.
24 From the CityMobil2 project we present central results from face-to-face interviews, an onsite-survey and two
25 focus groups. To further support the AV designers we describe and rate different design options to present the
26 information of the four categories, including the design of the infrastructure, the vehicle shape, the vehicle
27 manoeuvres and the external Human-Machine Interface (HMI) of the AV.

28 **Keywords:** Automated vehicles; interaction with other traffic participants; design considerations;
29 Vulnerable Road Users; external HMI

30 **1 Introduction**

31 There is currently a strong desire by manufacturers to introduce automated vehicles (AVs) to the market (see the
32 roadmap of the European Road Transport Research Advisory Council; ERTRAC 2017). These vehicles allow the
33 driver to hand over the complete dynamic driving task to the automation of the vehicle (SAE 3 and higher; SAE
34 International 2016). Examples of this trend are the activities of all main vehicle manufactures to provide
35 automation functionalities for their passenger vehicles. A slightly different solution for new forms of mobility
36 are Automated Driving System (ADS)-dedicated vehicles (see SAE International 2016) or Automated Road
37 Transport System (ARTS), that provide bus-shuttle or robotaxi-like services, operated completely driverless,
38 especially for the first and last mile of transport. In Europe, a number of active projects are currently
39 demonstrating and testing such systems, including the CityMobil2 project funded by the European Commission
40 (<http://www.citymobil2.eu> ; Alessandrini et al. 2014), the GateWay project in the UK ([https://gateway-](https://gateway-project.org.uk)
41 [project.org.uk](https://gateway-project.org.uk)), the WEpod project in the Netherlands (<http://wepods.com>), and first applications in Germany,
42 such as the test operation of automated shuttle busses from Deutsche Bahn (Saunders 2017).

43
44 Both privately owned and public forms of AVs are likely to be deployed in mixed traffic environments, and
45 therefore, need to interact safely and efficiently with other traffic participants, including conventional, manually
46 driven vehicles, cyclists, and pedestrians. As traffic participants, humans use multiple implicit cues to anticipate
47 the behaviour of vehicles on the road, such as the approaching speed of an oncoming vehicle. Other cues involve
48 explicit means of communication, such as eye contact and gestures, as well as vehicle-based signals, such as
49 brake lights or indicators. All these means of communication allow effective understanding and coordination of
50 future motion plans between different traffic participants. However, current AVs are thoroughly lacking such
51 communication and coordination capabilities, and their interaction with other traffic participants is often limited
52 to, and mostly dominated by, the rational principle of collision avoidance. This results in non-human-like
53 behaviour of the AV, such as sudden stopping, unexpected lane changes or long standstill periods (e.g. standstill
54 until a blocking obstacle moves away). These actions are not well predictable, and can be quite frustrating for
55 other traffic participants, leading to reductions in safety and efficient traffic flow (Brown & Laurier, 2017).
56 Instead, an AV's behaviour and future path of movement should be well understood by other traffic participants.
57 This allows the surrounding traffic participants to correctly interpret the intentions of the AV, and coordinate
58 their planned actions accordingly. To safely integrate AVs in mixed traffic environments, we need to ensure that
59 the common human-human interaction between the on-board driver and other traffic participants today is
60 replaced by an artificial interaction of the AV. This opens a completely new field for Human Factors researchers
61 and Human-Machine Interface (HMI) designers of AVs (Cacciabue et al. 2015).

62 In the future, the situation will change from a dyad of interaction today (on-board driver and other traffic
63 participants) to a triad of interaction (on-board user, AV and other traffic participants) in which the direct
64 interaction between the AV and the surrounding traffic participants will play a significant role (Figure 1). The
65 interaction between the AV and surrounding traffic participants, replacing some parts of the common human-
66 human interaction, needs to be newly developed as this will become most prominent. In the new triad of
67 interaction, the information needs of the on-board user of an AV should be also considered to avoid confusion
68 and unsafe situations (e.g. the on-board user gives additional signs to traffic participants or that other traffic
69 participants interpret the body language or gestures of users on board in a way they are used to, even though the
70 user on-board is not in charge of controlling the vehicle).

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FIGURE 1 ABOUT HERE

This paper focuses on how to design the interaction of the AV with other traffic participants. It presents some design considerations for designing the interactions of AVs with other traffic participants, based on current human-human interaction in mixed traffic environments. The paper is structured in the following way: In the first part, we describe our analysis of the common features in human-human communication between traffic participants. Based on this analysis we derived four categories of information that are presented in the second part of the paper as design considerations. These are 1) information about vehicle driving mode, 2) information about next manoeuvres, 3) information about perception of the environment and 4) information about cooperation capabilities. In the third part, we use the four categories of information to analyse available studies and data from face-to-face interviews, onsite questionnaires, and two focus group studies, which we conducted as part of the CityMobil2 project. These give a first insight into the needs and expectations of traffic participants interacting with AVs and the relevance of each of the four categories for the AV design. In the fourth and final part, we present an overview on existing AV design concepts from vehicle manufacturers, suppliers and research institutions and describe several methods on how relevant information can be transferred to surrounding traffic participants and we discuss their advantages and disadvantages.

The overall aim of the design considerations is to provide a structuring aid for designers, such as those developing external HMI (defined as the HMI of an AV that is meant to send information to surrounding traffic participants) and interaction concepts for AVs, to reduce the complexity of the design space and to support designers in their decisions so that traffic participants receive the most pertinent information from the AV, using the most appropriate communication channels.

2 Analysis of common interactions between traffic participants

When designing the behaviour of the AV in a mixed traffic environment, we assume that it is highly relevant to understand how human traffic participants currently interact with each other. This is in line with the work of other authors who analyse the current human-human behaviour to understand how an AV needs to be designed for safe implementation in mixed traffic scenarios (see Beggiato, Witzlack, & Krems, 2017; Färber 2016; Imbsweiler et al. 2017 a,b; Parkin et al. 2017; Portouli et al. 2014; Rasouli et al. 2017; Schneemann & Gohl 2016; Vissers et al. 2016).

According to Visser and colleagues (2016), day-to-day interaction between traffic participants is thought to be guided by five main factors: a) traffic rules, b) expectations, c) individual differences, d) behavioural adaptation, and e) informal rules & non-verbal communication. While traffic rules, individual differences and behavioural adaptations are factors that lie outside of what can be directly influenced by the AV designers, this paper focuses on documenting design considerations for the design of AVs that address *expectations* of traffic participants about the behaviour and reactions of AVs, as well as the *informal rules and non-verbal communications* currently in place for such interactions.

It is well known that the *expectations* of traffic participants have large influences on their decisions and actions in traffic (Houtenbos et al. 2004; Shor 1964). Björklund and Aberg (2005) report that traffic participants use traffic rules and design features of the road as well as the behaviour of other traffic participants as a basis for their expectations on how a traffic scene evolves. The behaviour of others consists of multiple implicit cues such as the vehicle's approach speed, gap size or lane deviation and these are used to anticipate the intentions of

111 others (Demiroz et al. 2015; Kitazaki, & Myhre 2015; Sucha et al. 2017; Várhelyi 1998; Zito et al. 2015). A
112 good example is the approaching behaviour of a vehicle at a pedestrian crossing. If the vehicle slows down this
113 could be interpreted as the beginning of a stopping manoeuvre and a signal that the vehicle will stop for the
114 pedestrians to cross (Rasouli et al. 2017; Schneemann & Gohl 2016). Additionally, the vehicle type and
115 appearance provide another source of information that forms expectations (Klatt et al. 2016). Due to its size, a
116 truck is associated with being slower than a sports car, but also likely more dangerous to collide with (Färber
117 2016). Thus, the vehicle type helps traffic participants to determine the general motion characteristics of a
118 vehicle and its driving style.

119 In addition, *informal rules and non-verbal communication* play an important role in situations where the traffic
120 rules lead to ambiguous situations, or where formal rules are replaced by informal ones. Informal rules are rules
121 that are often not in line with the official traffic rules, but that are established in the interactions between traffic
122 participants, such as yielding also for a cyclist at a pedestrian crossing (Bjørnskau 2017) or an informal first-
123 come-first-serve approach at some junctions (Ceunynck et al. 2013). In current traffic with conventional,
124 manually driven vehicles, other traffic participants use non-verbal communication, such as implicit cues such as
125 motion patterns and vehicle behaviour and explicit vehicle-based signals (e.g. flashing lights or turn signals) to
126 predict the next manoeuvres (Dey & Terken, 2017; Ba et al. 2015). Also, body language, such as head
127 orientation, nodding, hand gestures and eye-contact are taken into account to coordinate common actions of
128 traffic participants in specific situations (Guéguen et al. 2015; Kitazaki, S., & Myhre, N. J. 2015; Schneemann &
129 Gohl 2016; Sucha et al. 2017; Ren et al. 2016). These signals are especially important in complex situations or in
130 situations that need some form of cooperation such as urban environments. For example, Sucha et al. (2017) and
131 Schneemann and Gohl (2016) reported that pedestrians use a driver's non-verbal gestures and eye contact with
132 the driver as indicators beside the deceleration of a vehicle that a driver is giving them priority. Another study
133 explored the interaction of German drivers at bottleneck roads (Imbsweiler et al. 2017b). The authors found that
134 the drivers most often used the driving manoeuvre itself as well as the headlight flashes as explicit signals for the
135 coordination of their actions.

136 In all cases, the context of such information is important when interpreting its meaning, and the intention
137 conveyed by the same signal may vary, depending on the traffic situation and the behaviour of others (Savigny,
138 1995). For example, a flashing headlight may mean that a vehicle will wait for others to pass, e.g. at a bottleneck
139 road, or that it is giving a warning to other drivers. Thus, humans need to constantly interpret the communication
140 signals in light of the current driving context, in light of cultural norms (Färber 2016; Nordfjærn et al. 2014), and
141 on past experiences made in comparable traffic situations (Herslund & Joergsen, 2003).

142 As described in this section, specific means of communication are used between humans in today's traffic to
143 coordinate the interaction of different traffic participants. When introducing AVs in a mixed traffic environment
144 on today's roads, these automated vehicles need to provide some forms of communication to other traffic
145 participants, to allow for safe, smooth and intuitive interactions.

146 **3 Deriving design considerations for the design of the AVs' interaction from human-human interaction**

147 With the introduction of AVs in mixed traffic environments, designers are facing the challenge to design an
148 appropriate interaction strategy between the AV and other traffic participants. It seems likely that central
149 elements of the common human-human interaction need to be replaced by technical means for the AV-traffic

150 participant interaction. As human-human interaction is quite complex we extracted four categories of
151 information from the reported studies above. For this, we analysed which information human traffic participants
152 use to build their expectations of future vehicle behaviour and their decisions and what kind of information they
153 use to coordinate their actions. The categories are meant as a structuring aid for HMI designers in this complex
154 design space and are intended to help designers to understand which information is needed by other traffic
155 participants to successfully interact with an AV. The categories are defined as:

156 **Category A - Information about vehicle driving mode:** Based on the reported studies of Klatt et al. (2016) and
157 Färber (2016) on vehicle type and vehicle size we define a category named *vehicle driving mode* which includes
158 all information that activates specific schemata about AV characteristics. Information of this category supports
159 other traffic participants to develop the right expectations about the AV behaviour by informing others about the
160 vehicle driving mode, e.g. if the vehicle is driverless or driven in automated or manual driving mode.

161 **Category B – Information about the vehicle’s next manoeuvres:** A central element of conventional human-
162 human communication is the vehicle movement, for example changes in a vehicle’s trajectory, deceleration, and
163 acceleration and resulting changes in gap size (Björklund & Aberg 2005; Demiroz et al. 2015; Dey & Terken,
164 2017; Kitazaki, & Myhre, 2015; Sucha et al. 2017; Várhelyi 1998; Zito et al. 2015). Also vehicle-based signals
165 are taken into account by others to predict the next manoeuvres (Ba et al. 2015). Based on these results we
166 conclude that also an AV needs to provide information about its intentions that means about its next manoeuvres
167 to support other traffic participants to anticipate the current and future behaviour of the AV. This information is
168 summarized in the category *vehicle’s next manoeuvres*.

169 **Category C – Information about perception of environment:** In several situations vehicle movements (such
170 as vehicle deceleration) are interpreted as an indication that a driver has detected surrounding road users and is
171 willing to react to those. This expectation is becoming stronger even more when more explicit signals such as
172 eye contact between traffic participants and/or head orientation of the driver are taken into account in low speed
173 environments as indication that the driver has detected the traffic participant (Guéguen et al. 2015; Kitazaki, S.,
174 & Myhre, N. J. 2015; Schneemann & Gohl 2016; Sucha et al. 2017; Ren et al. 2016). Therefore, we define the
175 category *perception of environment* for the AV design that covers all information that helps others to understand
176 that they were detected by the AV. As common human-human communication is no longer available for AVs
177 this interaction needs to be replaced by technical means.

178 **Category D - Information about cooperation capabilities:** According to Vanderhaegen et al. (2006)
179 cooperation can be defined as managing the interference that can occur when two human agents each achieve
180 goals that can interfere with those of the other. In common human-human interactions in mixed traffic,
181 establishing explicit cooperation is often indicated by gestures, eye contact, or the use of headlight flashes in
182 addition to the adaptation of vehicle movements (Sucha et al. 2017, Imbsweiler et al. 2017). Therefore, we
183 conclude that there is also a need for AVs to inform other traffic participants about their capabilities to start
184 direct bilateral coordination of actions and to give advice to others regarding their next actions (e.g. give right-
185 of-way to other traffic participants; ask them to stop; advice pedestrians to cross etc.). This information is
186 summarized in the category *cooperation capabilities*.

187 Figure 2 summarizes the proposed categories of information for our design considerations.

188
189

FIGURE 2 ABOUT HERE

190 Based on the four extracted categories we analysed currently available research studies on communication needs
191 of traffic participants interacting with AVs as well as the results of the Citymobil2 studies to find out more about
192 the relevance of the categories for AV design. The results are documented in section 4.

193 **4 Communication needs of traffic participants interacting with AVs**

194 The communication needs of other traffic participants with regards to AVs are currently a very new and
195 unexplored field of research, where only results from a few relevant studies are available. This is partly based on
196 the absence of AVs on today's roads. However, the successful uptake, acceptance, and use of such vehicles in
197 the future depend on their ability to interact and cooperate successfully with other traffic participants. This
198 section provides the first insight into the communication needs of other traffic participants during their
199 interaction with AVs in a mixed traffic environment, based on a small number of completed studies in this area,
200 including data from the CityMobil2 project. The four categories defined in section 3 are used to structure the
201 analysis of results.

202 **4.1 Literature review**

203 **Category A – Information about vehicle driving mode:** Existing studies reveal that other traffic participants
204 expect to react and feel different in the presence of AVs compared to manually driven vehicles. Hagenzieker and
205 colleagues (2016) conducted an interview study with 29 cyclists, using photographs as stimulus material. The
206 participants were asked about their expectations and self-reported behaviours when interacting with
207 conventional, manually driven cars, compared to AVs. Results showed that the participants were quite
208 conservative, expecting to be detected more often when interacting with a manually driven vehicle than with an
209 AV. Different expectations and reactions of pedestrians were also reported by the AVIP project studies
210 (Lagström, & Malmsten Lundgren, 2015; Malmsten Lundgren et al. 2016). The authors explored whether
211 pedestrians were comfortable to cross in front of an AV (passenger vehicle) during a field study with a 'fake'
212 driver, and a questionnaire study using photographs. Here, the results revealed that pedestrians were less willing
213 to cross in cases where the "fake human driver" on board of the AV showed uncommon behaviour, such as
214 reading a newspaper or sleeping. This effect was even stronger when other traffic participants could not actually
215 see any driver in the vehicle because he was hidden using a specially adapted vehicle (Habibovic et al. 2016).
216 Thus, these authors conclude that there is a need for an AV to indicate that it is in automated mode to explain
217 uncommon behaviour of the human user on board. From the findings of both studies it can be concluded that it is
218 important to give surrounding traffic participants an indication that they share the road with an AV to induce
219 appropriate expectations and reactions. First results from real environment are reported by Brown and Laurier
220 (2017) who analysed several publicly available user videos of automated driving (up to SAE level 2). They
221 found several situations where other drivers were confused by the reactions of the automated vehicle and
222 conclude that an indication of the vehicle driving mode would help others to build appropriate expectations on
223 the AV behaviour.

224 However, there are contrary findings on the question if the vehicle driving mode needs (AV vs. manually driven
225 vehicle) to be displayed explicitly. Rothenbücher and colleagues (2016) report the results of a field experiment
226 with a Wizard-of-Oz passenger vehicle that looked driver-less to other traffic participants. In contrast to the
227 AVIP project studies, the authors did not find any safety concerns from the vulnerable road users (VRUs). They
228 documented normal crossing behaviour, based on a series of video recordings of these interactions, with hesitant

229 behaviour only observed when the vehicle misbehaved in some way. Another study also did not find any
230 differences when exploring the behaviour of drivers of conventional vehicles interacting with an AV (GATEway
231 Project 2017). In a simulator study of the GATEWAY project, the authors tested if drivers show different
232 driving behaviours in an intersection scenario and an urban carriageway scenario when the recognisability of the
233 AVs was varied (high visibility – sensors installed on a rack of the AV’s roof; low visibility – only sensors/no
234 rack installed on the AV’s roof) and compared this to conventional, manually driven vehicles (no sensors on the
235 vehicle’s roof). The results showed no differences in driving behaviour for the two scenarios, and subjective
236 reports revealed that drivers’ decisions were mainly based on vehicle behaviour related characteristics, such as
237 the gap size and assessment of safety, but not influenced by whether an AV or manually driven vehicle was
238 involved.

239 In addition, the implication of this information on the behaviour of other traffic participants is currently not fully
240 understood. Millard-Ball (Millard-Ball 2017) forecasts in a simulation that such indication of the vehicle driving
241 mode might lead to a negative behaviour adaptation of other traffic participants “playing” with the AVs, taking
242 more risky behaviour or stopping them intentionally.

243 **Category B – Information about next manoeuvres:** Lagström and Malmsten Lundgren (Lagström, &
244 Malmsten Lundgren, 2015; Malmsten Lundgren et al. 2016) reported in their above mentioned study that
245 pedestrians took the vehicle movements (such as approaching speed of the AV and standstill position) as
246 important indication for their decision to cross in front of the AV. Thus, they came to the conclusion that other
247 traffic participants would profit from information on current and future manoeuvres of an AV. This is also
248 supported by the studies of Rothenbücher and colleagues (2016) and the GATEway Project 2017 (reported
249 above) that did not find any effect of an explicit information of vehicle driving mode but showed that
250 surrounding traffic participants based their decisions on assumptions of next manoeuvres of AVs. This is in line
251 with another study that showed a main effect of gap size but did not find any effects of additional display
252 information for AVs (Clamann, Aubert, & Cummings 2016). Here, two different versions of a visual display
253 providing advice about crossing or information on vehicle manoeuvres (in this case continuous speed
254 information) were installed on an AV during a test track study. Results showed no differences in behaviour with
255 the “no display” condition, with participants basing their decision to cross mainly on gap size, followed by
256 vehicle speed. However, around 50% of the participants reported in a subjective interview that they would profit
257 from an additional display for AVs even though this did not influence their decision to cross in this study. The
258 need for explicit information was also reported in a study of Rodriguez (2017). She reports results from an
259 interview study, an online survey, and a focus group, conducted as part of the WEpod project. Among other
260 results, participants in this study expressed a need for information about the AV’s next manoeuvres, especially
261 regarding its turning and stopping behaviour of the complete driverless AV. That pedestrians benefit from
262 additional information of current and next vehicle AV manoeuvres was also shown in a study of Böckle et al.
263 (2017). The authors reported increased levels of self-reported safety and comfort when the AV indicated its
264 manoeuvre intention using light and acoustic signals.

265 **Category C – Information about perception of environment:** In the studies of the AVIP project (Lagström, &
266 Malmsten Lundgren 2015; Malmsten Lundgren et al. 2016) the authors report that pedestrians based their
267 decision to cross the road on driver-related cues – mainly on eye contact. In all conditions in which the fake
268 driver of the AV was distracted, sleeping or absent, participants reported that they decided not to cross the road
269 because they did not receive any cues from the driver that they were noticed and therefore felt unsafe.

270 Participants also reported that they may expect to get confirmation from the person on the driver seat even if the
271 vehicle is in an automated driving mode. The authors conclude that common gestures and eye contact might
272 need to be replaced by other forms of communication, such that other traffic participants can confirm they have
273 been detected by the AV.

274 **Category D – Information about cooperation capabilities:** In several situations there is no need and often no
275 opportunity for signals such as eye contact or the use of gestures in the human-human communication, e.g. at
276 night time. However, some complex traffic situations exist that require the coordination of actions between
277 traffic participants and thus, further information from the AV on its cooperation capabilities might be needed.
278 Imbsweiler et al. (2017b) conclude from their study results on human-human interaction that the combination of
279 implicit signals such as vehicle manoeuvres and explicit signals to inform others about the willingness to
280 cooperate would be most promising. This is in line with the results of Schneemann and Gohl (2016) who
281 reported that ambiguous traffic situations between drivers and pedestrians in low-speed environments are often
282 solved by using gestures and eye-contact. There is only one study known by the authors so far that tested a
283 display of the category *cooperation capabilities* for an AV. In their study mentioned above, Clamann et al.
284 (2016) tested a display variant giving advice that it is safe/not safe to cross for a pedestrian. It was tested against
285 a display variant with continuous speed information of the AV and no additional display information. The
286 authors did not find any effects of additional display information for AVs as participants based their decision to
287 cross on gap size. This could be an effect of the selected scenario where the most relevant information for the
288 crossing decision was gap size and no further information about cooperation capabilities were necessary.

289

290 **4.2 Overview of the CityMobil2 Studies**

291 The EU Project CityMobil2 was a pioneer project for exploring the live interaction of AVs and other traffic
292 participants in shared space (Alessandrini et al. 2014). The main focus of CityMobil2 was to realise a number of
293 showcases and demonstrations of ARTS in different European cities (Lausanne (Switzerland), La Rochelle
294 (France), Trikala (Greece), Oristano (Italy) and Vantaa (Finland)). These AVs (ADS-dedicated vehicles
295 according to SAE International 2016) were developed, tested and implemented in the respective cities, where
296 they offered an additional service to the local public transport system. The AVs drove without a driver, on fixed
297 routes through the city, interacting in mixed settings for some demonstrations (Italy, Greece, Switzerland and
298 France). For legal reasons, an operator was present at all times. The AVs were electric vehicles and looked like
299 small mini-busses (see Figure 3).

300

FIGURE 3 ABOUT HERE

301 To investigate the users' attitudes towards these vehicles and their interaction needs as pedestrians and cyclists, a
302 number of studies were conducted as part of the project. This began with a face-to-face interview study in
303 Braunschweig (Germany) and Leeds (UK), followed by an on-site questionnaire study administered during
304 demonstrations in La Rochelle, Lausanne, and Trikala. Finally, a focus group study was conducted with users of
305 the AVs in La Rochelle. For the validation of the four categories of our design considerations we analysed the
306 results of all three CityMobil2 studies to find out more about the specific needs of traffic participants interacting
307 with AVs. Results of the three studies are summarised below:

308 **4.2.1 CityMobil2 – Interview study**

309 **Main Objective:** Two interview studies were conducted in 2014 at the German Aerospace Center (DLR) and the
310 Institute for Transport Studies at the University of Leeds (ITS Leeds). Participants of the interview study had no
311 previous experiences with AVs and the main objectives of the interviews were to gain knowledge on where and
312 for whom AVs might be usefully implemented, which kind of interaction with the AV participants would expect,
313 and what kind of design they would prefer.

314 **Method:** Two semi-structured interviews were conducted, one in each location. A total of 26 participants took
315 part in the explorative face-to-face interviews (see details in Table 1).

316 TABLE 1 ABOUT HERE

317 All participants were in possession of a valid driving licence. Participants were paid for their participation
318 (interview duration of 40-60 minutes, 10€ per hour in Braunschweig, 15£ in total for participation in Leeds).
319 Both interviews were similar in their structure and started with an introduction of AVs and their capabilities
320 (using photo and video material). The interview consisted of three main sections: The first section dealt with
321 users' expectations regarding AVs. Here, we sought participants' views regarding where and for whom AVs
322 might be usefully implemented. In the second section, participants were shown pictures of different traffic
323 scenarios, and they were asked to imagine themselves in these situations, as either a cyclist, pedestrian or car
324 driver. They were then asked to suggest the expected behaviour of the AV, when interacting with them in these
325 situations, and also how they might interact with the AV. The scenarios were chosen to illustrate settings where
326 an interaction between different actors was required, and included: a) a pedestrian zone, b) intersection with
327 traffic lights, c) zebra crossing, d) intersection without traffic lights, e) bicycle track, and f) merging from a
328 minor to a major road. Participants were also asked what kind of additional information they would like to
329 receive from the AV in these specific traffic scenarios, in the absence of a human driver. In the third section of
330 the interview, participants were asked about their personal preferences regarding the design of interaction-related
331 information from the AV (e.g. what kind of communication channel or location for information would be
332 preferred by the participants?). As the focus of this paper is on AV design, only the results of interview sections
333 two and three are presented here.

334 **Results:**

335 **Category A – Vehicle driving mode:** Participants pointed out that they would like to be able to identify an AV
336 by its appearance [example statement: *An AV should be identified as an AV on first glance*]. Furthermore a
337 distinction between different types of AVs and their abilities regarding maximum speed was mentioned as
338 helpful to build up appropriate expectations [example statement: *What is the maximum speed? Is it an AV for the*
339 *city or for the motorway*].

340 **Category B – Vehicle manoeuvres:** The majority of participants at both interview sites pointed out that in clear
341 situations (regulated by traffic law and road infrastructure), they would expect the AVs to respect and obey the
342 traffic rules (scenario b, c and e). For example: While crossing the street as a pedestrian at a traffic light
343 (scenario b), all 26 participants would expect the AV to stop and participants did not see the need for additional
344 information presented by the AV that goes beyond the conventional, established communication behaviour.
345 However, in less structured environments, such as a zebra crossing or driving on a bicycle track, participants

346 seem to feel less safe and the majority would prefer additional information about the AV's behaviour [example
347 statements: *Maybe a light signal, so that I know it [the AV] will stop soon; A sign on the road that I know it [the*
348 *AV] will drive until there and not further.*]. In addition to these scenarios, participants mentioned that they would
349 appreciate to have additional information regarding the future behaviour of the AV while crossing the street
350 without traffic lights (scenario d) [example statement: *If [the AV] detected me, and will stop or decelerate. I*
351 *expect more from an AV than from a normal car.*].

352 **Category C – Perception of environment:** In multiple scenarios participants pointed out that they would like to
353 have information if they were detected by the AV. This was true for scenarios where the pedestrians had the right
354 of way (zebra crossing (a), traffic light (b)) [example statements: *Person detected ;"I [the AV] have detected*
355 *you*] and in scenarios where the AV had the right of way (intersection without traffic lights (d)) [example
356 statement: *Information that it [the AV] detected a human or an obstacle*]. Especially in scenario e (bicycle track)
357 where the participants should take the view of the cyclist they asked for an indication that they were detected by
358 the AV [example statement: *It would be perfect if there would be a picture or symbol for "cyclist detected" so I*
359 *would know that "I have been detected" and I would just ride on*].

360 **Category D – Cooperation capabilities:** In scenarios where the pedestrian had the right of way (zebra crossing
361 (a), traffic light (b)) participants mentioned that the AV could signalise when it is safe to cross [example
362 statement: *[..] At a specific distance a light on the AV will light up and it is safe to cross and if the light goes off*
363 *you cannot cross the zebra crossing [..]*]. Regarding the scenario where the pedestrian had not the right of way
364 but was instructed to imagine he/she would pass the street in front of the AV (intersection without traffic lights
365 (d)) participants would even expect some kind of reprehension by the AV to indicate that the AV is not willing
366 to cooperate [example statements: *I ran over the street and the AV honks at me [..]; maybe an acoustic signal*
367 *like "you know that I [the AV] am here, watch out, if you want to pass than hurry up*].

368 4.2.2 CityMobil 2 – On-site questionnaire study

369 **Main objectives:** While the interviews were conducted with participants who had little or no experience with
370 AVs, the on-site questionnaire recruited participants who had actually experienced interaction with the AVs
371 during the demonstrations of the vehicles provided by the EU Project CityMobil2. The questionnaire study was
372 developed to gain further insight on the factors important to road users in the interaction with AVs.

373 **Methodology:** The questionnaire was completed by 664 (386 male, 278 female) participants across the three
374 demonstration sites: La Rochelle, Lausanne, and Trikala (see Madigan et al. 2017; Madigan et al. 2016 for
375 further details). An important criterion for the participant selection was their knowledge regarding interactions
376 with the AV. Only participants who had interacted with the AV at least once were asked to complete the
377 questionnaire. Participants were recruited near the demonstration sites on a voluntary basis. The questionnaire
378 consisted of two parts. The second part (35 items), which is described in this paper, focused on understanding the
379 interaction of traffic participants with AVs. Participants were asked if they felt safe interacting with the AVs and
380 how this feeling of safety was influenced by different environmental factors (shared spaces vs. dedicated lanes).
381 Participants were also asked what kind of information they would wish to receive from the AV, regarding its
382 current and future behaviour.

383 **Results:** As the results of the study are presented in Merat et al. (in press), we provide a brief overview of these
384 for the purpose of this paper.

385 **Category A – Vehicle driving mode:** There are no results on this category as the CityMobil2 vehicles were
386 easily recognizable as driverless, ADS-dedicated vehicles with no driver on board. Thus, this category was not
387 assessed in the questionnaire study.

388 **Category B – Vehicle manoeuvres:** Overall, the main findings from this study showed a significant difference
389 in traffic participants' needs and expectations with regards to the vehicle manoeuvres when the AVs were
390 demonstrated on a dedicated track vs. a shared space. Results showed that in the presence of road markings,
391 participants believed that the AV had priority, but that when there were no road markings they, as pedestrians,
392 had priority and the right of way. Regarding information about the manoeuvre of the AV, participants reported a
393 greater need for information about the behaviour of the AV (whether it is stopping, turning, going to start
394 moving) in the absence of road markings or dedicated tracks for the AV. Participants ranked information about
395 whether the AV is stopping, turning, and starting as more important than information about the AV's current
396 travel speed. This is possibly because (due to safety reasons in a mixed traffic environment) the vehicles
397 travelled at quite a slow speed (around 10 km/h), but also because this information is perhaps easier to observe
398 than the intentions of the AV.

399 **Category C – Perception of environment:** Participants from all three locations rated information about the
400 perception of the environment, e.g. confirming they had been detected as important information from the AV,
401 again highlighting the importance of feeling safe when interacting with these vehicles.

402 **Category D – Cooperation capabilities:** There are no results on this category as this category was not assessed
403 in the questionnaire study.

404 **4.2.3 CityMobil 2 – Focus group study**

405 **Main Objectives:** To gain further insight in people's attitudes towards AVs two focus group discussions were
406 conducted in La Rochelle in 2015, approximately a month after the end of the demonstrations. The main
407 objective of the two focus groups was to understand and collect further insights regarding the experience of
408 participants during their daily interaction with the AV.

409 **Method:** Nine male and eleven female participants took part in the focus group discussions, which were
410 conducted separately, on the same day, by two French facilitators. The groups were divided by gender to avoid
411 any gender-based effects of mixed group discussions. All participants were residents of La Rochelle, and
412 confirmed that they had interacted with the AV at least once during the demonstration period. The experience of
413 participants with the AV was discussed in the focus group setting. The focus groups were both audio and video
414 recorded, and the following transcription and translation to English was done by a qualified transcriber and
415 translator. Analysis involved categorising participants' statements (Braun & Clarke 2006) into seven different
416 categories, with regards to (a) the AV in general, (b) the manoeuvre communication of an AV, (c) the
417 environment perception capabilities of the AV, (d) the cooperation and interaction strategies of an AV, (e) the
418 safety and traffic rules for an AV, (f) the influence of infrastructure (e.g. dedicated roads, lane markings) for an
419 AV and (g) the design (e.g. appearance, size) of an AV. Only the results for a, b, c, d and g are reported in the
420 following as they are of highest relevance for the categories of the design considerations.

421 **Results:**

422 **Category A – Vehicle driving mode:** Participants pointed out that it is important for the design of the AV (g) to
423 look unlike normal public transport systems to be clearly identified as an AV [example statements: “*For me, the*
424 *fact that it looks like a bus is bad.*”, “*It must break with the typical model for buses.*”]. Participant expressed the
425 importance of the AV design to build up the right expectations on the behaviour and next manoeuvres of the AV.
426 Participants pointed out that, if an AV is too symmetric in its appearance/format it will be hard to distinguish
427 between the front and the back of the AV, which make a prediction of the moving direction harder [example
428 statements: “[...] *when the vehicle is at a stop, you don't really know in which direction it's about to set off. And*
429 *when you're a pedestrian or a cyclist or you have a pram, even if it's not going fast, you don't really know in*
430 *which direction.*”, “[...] *outside of the reserved lanes, it's true that the direction isn't clear.*”]. Furthermore, a
431 futuristic design of an AV could also attract people to use an AV [example statements: “*If we want people to*
432 *ride in it, it must be cool, attractive, sexy. Nobody wants to ride in it now, because it's not attractive.*”].

433 **Category B – Vehicle manoeuvres:** When participants were asked if they required any specific information
434 about the AV in general (a) and about the AV's manoeuvres (b), they reported that they expected AVs to have at
435 least the same signals as common vehicles for indicating the next vehicle manoeuvre (e.g. indicator, brake lights,
436 horns) [example statement: “*Like for a car. I think it [the vehicle] should have the same signals as on an*
437 *ordinary vehicle.*”]. In case that the AV would be an electric vehicle such as those implemented within
438 CityMobil2, participants expressed their need to have additional signals so that the approaching vehicle could be
439 recognised more easily than it was the case in the CityMobil2 demonstrations [example statements: “*It's like*
440 *people on bicycles, because when you're a pedestrian you don't hear them coming, and I'm often startled by*
441 *cyclists on the pavement, and it's the same here with the vehicle (AV).*”, “*I'm for anything that can help with*
442 *signage. The fact that there's no noise is a big plus, it should be retained. So I think that other signalling*
443 *methods should be found*”]. Participants also mentioned that priorities and traffic rules for AVs (e) are unknown
444 by most of the traffic participants making it hard for them to predict next manoeuvres [example statements:
445 “*Which is why there should be rules. [...] In this case, the vehicle is new, and in the middle of traffic, it's*
446 *motorised, and no one knows the rule to follow.*”]. Regarding the influence of infrastructure (f), participants
447 reported that they would feel safer if the AV was driven on a clearly marked and predefined track, so that traffic
448 participants could anticipate where the AV will go next [example statement: “*I also noticed that there are no*
449 *route markings, and that you don't really know where it's going. It is a bit of a hassle, especially when you're on*
450 *a big square where everyone is walking.*”].

451 **Category C – Perception of environment:** Regarding information about environment perception of the AV (c),
452 interviewees pointed out, that they would like to know if they were detected. This might be caused by a general
453 lack of knowledge of how the technical system works [example statements: “*Isn't there a system that allows it to*
454 *detect that others are present?*”]. Participants did not express a general need for signals for all obstacles
455 detected, but discussed that it would be helpful if the AV could warn pedestrians when they are moving in its
456 way [example statement: “[...] *like the buses - when a pedestrian is in the way, they have a kind of sound signal*
457 *that warns the pedestrian that the bus is coming.*”].

458 **Category D – Cooperation capabilities:** Regarding the cooperation and interaction strategies of an AV (d),
459 participants mentioned that they would benefit from additional information for interaction with the AV that

460 could help to coordinate their actions [example statements: “Often, this happens with eye contact. You work out
461 whether you should give way or not, and in this case, you don't know, so there is doubt about whether to yield or
462 not.”, “Colour codes that indicates: Now I have right of way, now I don't, as if you were interacting with a kind
463 of driver.”].

464 **4.3 Summary of results on communication needs of other traffic participants interacting with AVs**

465 In the following the results of the literature review and the CityMobil2 studies are summarized for each of the
466 four categories of information.

467 **Category A: Information about vehicle driving mode**

468 The few research studies available so far show mixed results with regards to the need of traffic participants for
469 explicit information about the vehicle type (see section 3). In the research study of Lagström and Malmsten
470 Lundgren (Lagström, & Malmsten Lundgren 2015), Brown and Laurier (2017) and in the CityMobil2 studies
471 participants expressed their need to understand that the vehicle is driven in an automated mode while the
472 GATEway study (2017) did not find any effect of such indication on the driving behaviour of surrounding
473 drivers. In situations where the vehicle was driven completely driverless (CityMobil2 studies), the user on board
474 behaved unexpectedly (e.g. reading the newspaper; see Lagström and Malmsten Lundgren 2015) or the vehicle
475 showed unexpected behaviour (Brown & Laurier 2017) there was a need for additional information about the
476 vehicle driving mode. However, the implication of this information on the behaviour of other traffic participants
477 is currently not fully understood (Millard-Ball 2017). Thus, there is little knowledge so far if the category of
478 information on vehicle driving mode provides advantages or disadvantages when implementing AVs into mixed
479 traffic environments. It is also not known yet if other traffic participants need to distinguish between lower (SAE
480 level 2 to 3) and higher levels of automation (SAE 4 to 5) and driverless, ADS-dedicated vehicles. Further
481 research on how an indication of the vehicle driving mode influence the behaviour of surrounding traffic
482 participants is needed. Designers should consider this category carefully in their design and decide depending on
483 the envisioned application of their AV if information on the vehicle driving mode is needed.

484 **Category B: Information about AVs' next manoeuvres**

485 This category includes all information that supports other traffic participants to anticipate the current and future
486 vehicle manoeuvres. Applied to AVs, all study results summarised in section 3 show that these conventional
487 communication means, and the vehicle behaviour itself, are of significant importance for providing other traffic
488 participants with information about future AV manoeuvres, and supporting their decision making process. This
489 could be also supported by explicit indication of next manoeuvres by new external HMI (Böckle et al. 2017;
490 CityMobil2 studies). Also, dedicated environments for AVs help others to better predict next manoeuvres as the
491 AVs are running on dedicated tracks. Thus, information about an AV's next manoeuvres is of central importance
492 for the safe interaction with AVs in mixed traffic environments and should be considered by designers in any
493 case.

494 **Category C: Information about AVs' perception of the environment**

495 All information that helps other traffic participants predict if the AV has detected them is summarised in this
496 category. For AVs, the communication that is based on the signals of the driver on-board is no longer available,
497 and needs to be replaced by technical means. In the research study of Lagström and Malmsten Lundgren
498 (Lagström, & Malmsten Lundgren 2015) and in the CityMobil2 studies (see section 3.2), participants stressed
499 their needs to understand if the AV has detected them or not. In contradiction to that Rothenbücher et al. (2016)

500 found normal crossing behaviours of pedestrians when interacting with a driverless vehicle and conclude that
501 designers can avoid signals to replace, e.g. the conventional eye-contact between humans, and only need to
502 provide some explicit design for the minority who are irritated by the fact that they cannot see a driver on board.
503 Thus, based on what we know from research so far, designers need to decide from case to case, and for their
504 specific AV application if, and when, information on the AV's perception of the environment is required. It also
505 seems very important that the information given by the AV is not contradicted by the on-board user of the AV.
506 This could be particularly problematic if other traffic participants use the body language or gestures of the user
507 on board for deciding their next actions, especially if this information is in conflict with the AV's intention.
508 Anecdotal evidence, observed in the CityMobil2 trials, illustrated frustrations and near miss scenarios in such
509 circumstances.

510 **Category D: Information about AVs' cooperation capabilities**

511 While category C covers only the status information on the AV's perception of the environment, category D
512 goes one step further. It includes all information that an AV can send to other traffic participants to start a direct
513 bilateral coordination of actions and to give advice to them regarding their next actions. Participants in the
514 CityMobil2 studies explained that they would benefit from any information regarding whether they are allowed
515 to cross or not, whereas participants of the study conducted by Clamann and colleagues (Clamann, Aubert, &
516 Cummings 2016) did not benefit from any advisory information on an external display. In general, there is
517 currently no consensus as to whether AVs should be allowed to establish explicit cooperation by giving explicit
518 advice to others about their next actions as humans do today, or should stick to pure intention based information
519 about its next manoeuvres (Andersson et al. 2017). There is also a risk that the AV will provide false or at least
520 risky advice to other traffic participants, and it is also challenging to know which traffic participant is the target
521 of such information. Therefore, an understanding of how to provide context and individually specific advice may
522 be required for such scenarios.

523 Summing up, the relevance of each of the four categories can vary between different traffic situations and
524 vehicle applications – some categories of information are highly relevant, while others are either not relevant or
525 are less relevant for the safe interaction in specific traffic situations. Thus, the intention of the authors is not to
526 take the four categories of information as strict requirements that need to be addressed in every case, but rather
527 as an important design guideline for inspiring the design process. The designers of AVs should think carefully
528 about which categories of information are essential, which are not relevant for specific traffic situations, and
529 which design options are appropriate to transfer the relevant information. Future research will also provide us
530 with further insight into what information is needed in specific traffic situations, allowing a continuous update of
531 the communication needs of other traffic participants with AVs.

532 **5 Design options for the transfer of information**

533 In this final section of the paper, we provide an overview of the different design options that AV developers and
534 designers will need to consider, in order to relay the information outlined by our design considerations. A limited
535 number of design concepts and patents for AVs have already been investigated and published by industry and the
536 research community. Here, we consider some examples (as of mid-2017) on the basis of our proposed four
537 design options: i) the design of the infrastructure, ii) the design of the vehicle shape, iii) the design of vehicle
538 behaviour, and iv) the design of external HMI elements for visual and acoustic communication. Table 2 gives an

539 overview of the chosen design options, per design concept or patent. As illustrated below, most design concepts
540 relate to vehicle-based design elements. However, especially for driverless, ADS-dedicated vehicles the design
541 of the infrastructure is used to provide other traffic participants with the relevant information about an AV. The
542 design options listed below come along with different advantages and disadvantages (see section 5.1 for a
543 detailed discussion) and should be considered carefully by the design team.

544

545 **i) Design of infrastructure** - Designing the infrastructure (such as marked lanes, specific road signs, or physical
546 separation of tracks) could support other traffic participants to understand the driving mode of the vehicle
547 (Category A of the design considerations) and what kind of manoeuvres are possible by the AV (Category B).
548 Separated and/or marked lanes for AVs make it easier for other traffic participants to predict the path of the AV.
549 Systems such as CityMobil2 applications on demonstration sites (see CityMobil 2, Alessandrini 2016), the
550 Rivium Group Rapid Transit (2getthere 2017b) and the Personal Rapid Transit in Masdar City (2getthere 2017a)
551 use especially prepared infrastructure to allow for safe operation of fully automated vehicles. This is in line with
552 the results of the CityMobil2 studies, where participants mentioned that dedicated tracks and corresponding road
553 markings would help them identify the path of the AV, increasing their feeling of personal safety, because they
554 were able to predict the next manoeuvres of the AV.

555 **ii) Design of the vehicle shape** - Designing the vehicle shape can support comprehension of the vehicle's driving
556 mode (Category A), and an ability to identify the AV in the external environment. One of the most well-known
557 examples of an AV that does not look like a passenger vehicle is the Google car, a vehicle that has a very
558 characteristic “bubble” shape, which allows it to be easily identified as an AV (Waymo 2017). The same is true
559 for AV shuttles that can be easily detected as driverless, ADS-dedicated vehicles since they do not have a
560 conventional driver seat on board, and look different to a conventional passenger vehicle or bus (Alessandrini
561 2014; 2getthere 2017a; 2getthere 2017b). The design of the vehicle's shape can also support or hinder the
562 prediction of manoeuvres (Category B). For example, from CityMobil2 research we know that symmetric
563 vehicle shapes make it much harder for other traffic participants to predict the direction of travel, since the
564 forward and rear view look identical, allowing travel in both directions.

565 **iii) Design of vehicle behaviour** - The adequate design of vehicle behaviour, such as an indication of its
566 intention to accelerate, decelerate or change direction (Category B), provides other traffic participants with an
567 understanding of its manoeuvres, which is especially critical in shared space. The appropriate design of vehicle
568 manoeuvres also influences the behaviour of surrounding traffic participants and increase traffic efficiency and
569 cooperation (Sadigh et al. 2017). Vehicle movements might also be used by other traffic participants to interpret
570 if they have been detected (Category C). For example, if the AV slows down when approaching a zebra crossing,
571 other traffic participants might assume that the AV will stop and that this is because they were detected. Some
572 authors suggest that AVs should mainly be based on transferring information to other traffic participants by
573 designing appropriate vehicles manoeuvres and not putting too much focus on extra HMI (Risto, Emmenegger,
574 Vinkhuyzen, Cefkin, & Hollan 2017).

575 **iv) Design of HMI elements for the visual and acoustic communication** - The design of Human-Machine
576 Interface (HMI) elements can help transfer relevant information, using the visual or acoustic communication
577 channels. Visual information can either be sent in the form of text messages, icons or light patterns displayed on
578 the AV or projected on the road. While visual signs in the form of lights might be used to inform other traffic
579 participants about the vehicle driving mode and vehicle manoeuvres (Category A and B), visual text messages or

580 icons might be chosen to address only one specific recipient and provide advice on ensuing actions (Category C
581 and D). The same is true for audio signals, where generic audio signals might be used to address all other traffic
582 participants in the surrounding area. Compared to that, spoken words can be chosen to give some kind of specific
583 information or advice such as “Walk; AV is stopping” to inform other traffic participants about the AVs’
584 intentions (Category B) and cooperation capabilities (Category D).

585
586 With regard to concepts and prototypes being considered by vehicle manufactures, almost all make use of
587 additional visual and acoustic communication. Specific HMI messages such as text, signs or light patterns are
588 applied to help others identify the vehicle driving mode (see AVIP - Lagström, & Malmsten Lundgren 2015;
589 Concept-I from Toyota - Fink 2017; BMW Vision Next 100, 2016; FORD, 2017). In addition to conventional
590 communication devices such as indicators, brake lights, rear lights and sounds, AV design concepts often make
591 use of additional HMI devices to inform others about the AVs’ next manoeuvres. These are displayed at the front
592 and rear of the car (F015 - Mercedes Benz 2017; Nissan IDS Concept 2017; AVIP - Lagström, & Malmsten
593 Lundgren 2015; Duke University - Clamann, Aubert, & Cummings 2016; Semcon Smiling Car - Semcon 2017;
594 Google US9196164B1 patent - Urmson et al. 2015; Concept-I Toyota - Fink 2017, FORD, 2017), or devices that
595 project information on the road surface (Mitsubishi Road-Illuminating Directional Indicators - Mitsubishi
596 Electric 2015; F015 - Mercedes Benz 2017) to inform others about the vehicle’s next manoeuvres, the perception
597 of the environment or cooperation capabilities and advisory information. For some concepts, acoustic
598 information is also used to provide sound signals or spoken words (F015 - Mercedes Benz 2017; Google patent -
599 Urmson et al. 2015).

600 Table 2 provides an overview which design options are suitable for the transfer of information.

601

602 TABLE 2 ABOUT HERE

603

604 As mentioned above some design concepts and patents for AV already provide first insight by which technical
605 means other traffic participants could gather information from the AV. Table 3 summarizes the addressed
606 categories of information and the chosen design options per existing AV design concept.

607

608 TABLE 3 ABOUT HERE

609

610 **5.1 Assessment of different design options**

611 The design options described in section 5 above are meant to be used as guidelines for designers to work on an
612 appropriate design for AVs. Depending on the specific purpose of the AV, and the traffic environment in which
613 the AVs will be implemented, some design options might be favoured over others. Table 4 gives an overview of
614 some of the benefits and disadvantages that each design option is likely to provide. In addition, the technical
615 feasibility of the design options needs to be considered. Some of the Human Factors related disadvantages, such
616 as strong limitations for visually impaired people of visual signals, can be overcome by including multi-modal
617 solutions, which are likely to improve the interaction and cooperation between the AV and other traffic
618 participants. This is of utmost importance as the AV design should be inclusive and consider various groups of
619 traffic participants, e.g. disabled people, children with no reading skills or elderly people. However, we assume
620 that it is not necessary to display all relevant information on the visual or acoustic communication channel, but to

621 only use these channels to support the interaction in specific traffic situations. To support these messages,
622 essential information can also be relayed via specific infrastructure design, the vehicle shape and the appropriate
623 design of vehicle behaviour. Vehicle behaviour is already used as one of the main sources to allow for safe
624 interaction between traffic participants. In any case, for a multi-modal approach of external HMI and vehicle
625 behaviour, the chosen design should be well aligned and appropriately synchronised. This means that the
626 vehicle behaviour should be in line and timely synchronized with the information sent by the external HMI
627 elements, and not contradicted by any on-board users/operators. This will require an understanding of the timing
628 for the presentation of HMI messages, and the control of the AV manoeuvres. In addition, from a Human Factors
629 perspective, it will be important for vehicle manufacturers to agree on the same standards especially for the
630 design of new external HMI (Emmenegger et al. 2016).

631

632

TABLE 4 ABOUT HERE

633

634 **6 Summary and conclusion**

635 While developments in AV technology are occurring very rapidly, one of the great challenges facing engineers,
636 designers and Human Factors researchers in this area is an understanding of how we can integrate AVs in mixed
637 traffic environments, in a safe and intuitive manner. To achieve a better understanding of the needs of other
638 traffic participants, we analysed existing research knowledge on the common human-human interactions in
639 mixed traffic settings, as well as we considered some preliminary research results on the needs from other traffic
640 participants interacting with AVs, obtained primarily from the CityMobil2 project. On this basis, we describe the
641 design considerations covering four categories of information that designers can use for their design work in this
642 context. The considerations cover information on vehicle driving mode, manoeuvres, perception of the
643 environment and cooperation capabilities. These categories reflect the expressed needs of other traffic
644 participants in the vicinity of the AV, supporting the safe interaction of all actors. The design considerations are
645 intended to help designers of AVs to structure the complexity of the design space and provide support for finding
646 appropriate design solutions to assist such interactions. Our preliminary understanding is that there is currently
647 no single solution that applies to all traffic situations and vehicle types, as the requirements for the interaction
648 design are high, and the implementation scenarios for AVs are still highly versatile. Designers must therefore
649 consider the relevant information, based on the deployment setting of the AV. As AVs become more
650 commonplace, and are deployed more widely, such considerations may also help provide guidance for
651 manufacturers and designers who wish to work on standardising some of the above factors. Such a
652 standardisation is likely to help ensure appropriate use, trust and uptake of these vehicles, and ultimately
653 safeguard improvements in road safety.

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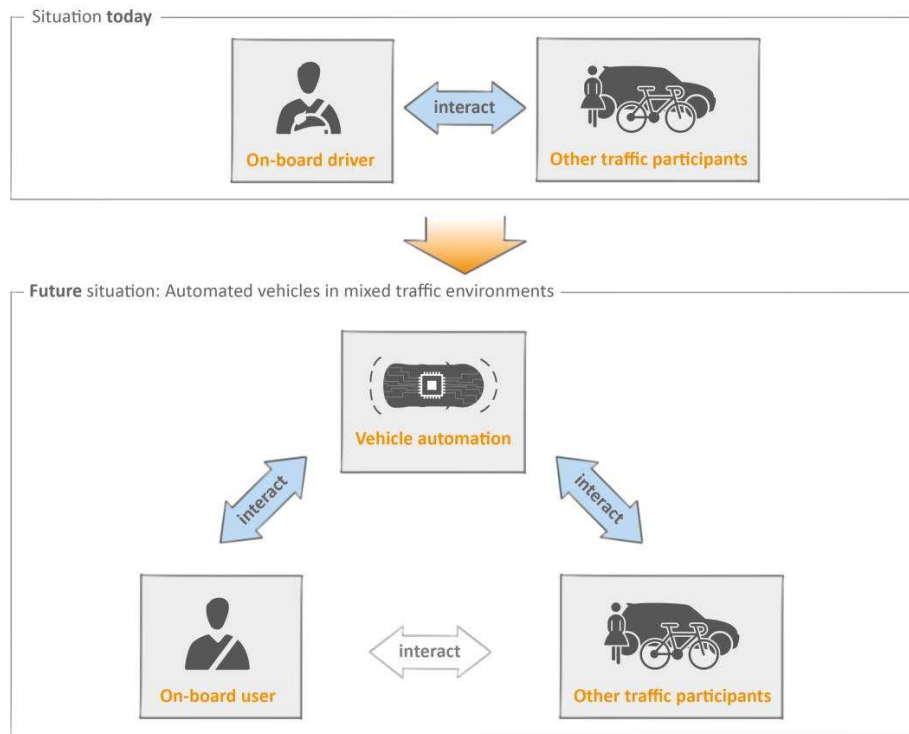
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829 **Acknowledgement**

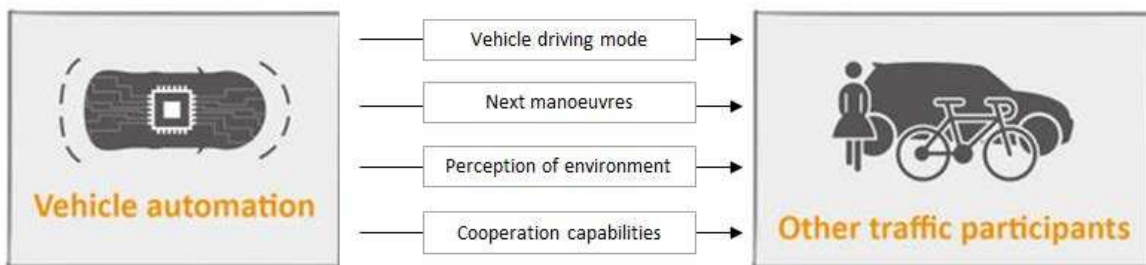
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Figure 1: From today's situation of human-human interaction in mixed traffic environments towards a future situation with a triad of interaction between automated vehicles, other traffic participants and the on-board users (source: EU project interACT)



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Figure 2: The four main categories of information in the proposed design considerations for AV interaction with other traffic participants



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Figure 3: ADS-dedicated vehicles used for the CityMobil2 showcase in La Rochelle

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847 **Table 1: Number, gender and age range of participants in the interview studies at DLR and ITS Leeds**

| | No. of male participants | No. of female participants | Age range |
|------------------|--------------------------|----------------------------|----------------|
| DLR | 7 | 7 | 21 to 50 years |
| ITS Leeds | 6 | 6 | 24 to 61 years |

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849 **Table 2: Categories of information and suitable design options to transfer information (marked with “+”)**

| | Category A: vehicle driving mode | Category B: next manoeuvres | Category C: perception of environment | Category D: cooperation capabilities |
|---------------------------|----------------------------------|-----------------------------|---------------------------------------|--------------------------------------|
| Infrastructure | + | + | | |
| Vehicle shape | + | + | | |
| Vehicle manoeuvres | | + | + | |
| External HMI | + | + | + | + |

Table 3: Overview on addressed category of information and chosen design options (marked with *) of some existing AV design concepts (as of mid-2017)

| Design concepts/patent | Categories of information | | | | Design options | | | | | | | |
|------------------------|----------------------------------|-----------------------------|---------------------------------------|--------------------------------------|----------------|---------------|-------------------|-------------|---------|-------------------------|---------------|--------|
| | Category A: vehicle driving mode | Category B: next manoeuvres | Category C: perception of environment | Category D: cooperation capabilities | Infrastructure | Vehicle shape | Vehicle behaviour | HMI: visual | | | HMI: acoustic | |
| | | | | | | | | text | symbols | light patterns & colour | spoken words | sounds |
| CityMobil 2 vehicles | * | * | | | * | * | | | | | | |
| Rivium PRT | * | * | | | * | * | | | | | | |
| GRT Masdar | * | * | | | * | * | | | | | | |
| Mercedes Benz F015 | * | * | * | * | | | | * | * | * | * | * |
| Nissan IDS Concept | | * | * | * | | | | * | | * | | |
| Toyota Concept-I | * | * | | | | | | * | * | | | |
| FORD Concept | * | * | | | | | | | | * | | |
| BMW vision 100 | * | | * | * | | | | | | * | | |
| Mitsubishi Electronic | | * | | | | | | | | * | | |
| Semcon Smiling Car | | | * | * | | | | | * | | | |
| Google Patent | | * | * | * | | * | | * | * | * | * | * |
| AVIP | * | * | | | | | * | | | * | | |

| | | | | |
|-----------------|---|---|---|---|
| Duke University | * | * | * | * |
|-----------------|---|---|---|---|

851 **Table 4: Overview of advantages and disadvantages of the different design options**

| Design option | Advantages | Disadvantages |
|-----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Infrastructure | <ul style="list-style-type: none"> - Reduces the number of potential conflicts when separated lanes are used - applicable in high-speed and low-speed scenarios - dedicated tracks increase feeling of safety | <ul style="list-style-type: none"> - Expensive - Lengthy implementation process - Limits AV to specific areas - Requires local or national government buy-in |
| Vehicle shape | <ul style="list-style-type: none"> - AV can be recognised as clear sender of information - applicable in high-speed and low-speed scenarios | <ul style="list-style-type: none"> - Manufacturer specific – not standardised - No differentiation possible for vehicles with multiple automation levels |
| Vehicle behaviour | <ul style="list-style-type: none"> - Similar to common interaction - AV can be recognised as clear sender of information - applicable in high-speed and low-speed scenarios | <ul style="list-style-type: none"> - Cultural differences in expected vehicle behaviour – large variations that make it difficult to standardised |
| Visual HMI: text | <ul style="list-style-type: none"> - Specific meaning can be transferred - AV can be recognised as clear sender of information | <ul style="list-style-type: none"> - Language skills necessary - Reading skills necessary - Other traffic participants need to look at the AV - Strong limitation for visually impaired traffic participants - Cannot display detailed information - The sizing of the display must be large to be viewed at distance - not applicable in high-speed scenarios - Overloading when used by several AVs on the road |
| Visual HMI: light patterns | <ul style="list-style-type: none"> - No language skills necessary - AV can be recognised as clear sender of information | <ul style="list-style-type: none"> - Meaning of light patterns not intuitive - Other traffic participants need to look at the AV - Strong limitation for visually impaired traffic participants - Some standardisation needed - Visibility of symbols may be reduced in poor weather or very bright sun - worse applicable in high-speed scenarios - Overloading when used by several AVs on the road |
| Visual HMI: symbols/icons | <ul style="list-style-type: none"> - No language skills necessary - AV can be recognised as clear sender of information | <ul style="list-style-type: none"> - Meaning of symbols not always intuitive - Other traffic participants need to look at the AV - Strong limitation for visually impaired traffic participants - Some standardisation needed - The sizing of the display must be large to be viewed at distance - worse applicable in high-speed scenarios - Overloading when used by several AVs on the road |
| Acoustic HMI: spoken words | <ul style="list-style-type: none"> - Specific meaning can be transferred - Other traffic participants do not need to look at the AV | <ul style="list-style-type: none"> - Language skills necessary - Strong limitation for hearing impaired traffic participants - AV as sender more difficult to detect - Not applicable for communication over far distances; not applicable in high-speed scenarios - Not targeted at specific traffic participants - May cause noise pollution - Overloading when used by several AVs on the road |
| Acoustic HMI: | <ul style="list-style-type: none"> - No language skills necessary | <ul style="list-style-type: none"> - Strong limitation for hearing impaired traffic |

| | | |
|---------------|------------------------------------------------------------|-----------------------------------------------------------------------------------------------|
| sounds | - Other traffic participants do not need to look at the AV | participants |
| | | - Poorly applicable in noisy environments |
| | | - No specific meaning |
| | | - Not applicable for communication over far distances; not applicable in high-speed scenarios |
| | | - AV as sender more difficult to detect |
| | | - Not targeted at specific traffic participants |
| | | - May cause noise pollution |
| | | - Overloading when used by several AVs on the road |

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