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Article:

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-

41   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).

71   FIGURE 1 ABOUT HERE

72

73   This paper focuses on how to design the interaction of the AV with other traffic participants. It presents some

74   design considerations for designing the interactions of AVs with other traffic participants, based on current

75   human-human interaction in mixed traffic environments. The paper is structured in the following way: In the

76   first part, we describe our analysis of the common features in human-human communication between traffic

77   participants. Based on this analysis we derived four categories of information that are presented in the second

78   part of the paper as design considerations. These are 1) information about vehicle driving mode, 2) information

79   about next manoeuvres, 3) information about perception of the environment and 4) information about

80   cooperation capabilities. In the third part, we use the four categories of information to analyse available studies

81   and data from face-to-face interviews, onsite questionnaires, and two focus group studies, which we conducted

82   as part of the CityMobil2 project. These give a first insight into the needs and expectations of traffic participants

83   interacting with AVs and the relevance of each of the four categories for the AV design. In the fourth and final

84   part, we present an overview on existing AV design concepts from vehicle manufacturers, suppliers and research

85   institutions and describe several methods on how relevant information can be transferred to surrounding traffic

86   participants and we discuss their advantages and disadvantages.

87   The overall aim of the design considerations is to provide a structuring aid for designers, such as those

88   developing external HMI (defined as the HMI of an AV that is meant to send information to surrounding traffic

89   participants) and interaction concepts for AVs, to reduce the complexity of the design space and to support

90   designers in their decisions so that traffic participants receive the most pertinent information from the AV, using

91   the most appropriate communication channels.

92   **2   Analysis of common interactions between traffic participants**

93   When designing the behaviour of the AV in a mixed traffic environment, we assume that it is highly relevant to

94   understand how human traffic participants currently interact with each other. This is in line with the work of

95   other authors who analyse the current human-human behaviour to understand how an AV needs to be designed

96   for safe implementation in mixed traffic scenarios (see Beggiato, Witzlack, & Krems, 2017; Färber 2016;

97   Imbsweiler et al. 2017 a,b; Parkin et al. 2017; Portouli et al. 2014; Rasouli et al. 2017; Schneemann & Gohl

98   2016; Vissers et al. 2016).

99   According to Visser and colleagues (2016), day-to-day interaction between traffic participants is thought to be

100   guided by five main factors: a) traffic rules, b) expectations, c) individual differences, d) behavioural adaptation,

101   and e) informal rules & non-verbal communication. While traffic rules, individual differences and behavioural

102   adaptations are factors that lie outside of what can be directly influenced by the AV designers, this paper focuses

103   on documenting design considerations for the design of AVs that address *expectations* of traffic participants

104   about the behaviour and reactions of AVs, as well as the *informal rules and non-verbal communications*

105   currently in place for such interactions.

106   It is well known that the *expectations* of traffic participants have large influences on their decisions and actions

107   in traffic (Houtenbos et al. 2004; Shor 1964). Björklund and Aberg (2005) report that traffic participants use

108   traffic rules and design features of the road as well as the behaviour of other traffic participants as a basis for

109   their expectations on how a traffic scene evolves. The behaviour of others consists of multiple implicit cues such

110   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   FIGURE 2 ABOUT HERE

189

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 where 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'sroof). 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 were 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."*].

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.

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.

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.

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 US9196164B1patent - 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.

654   7   References

655 2getthere (2017a) Masdar City PRT. https://www.2getthere.eu/projects/masdar-prt/. Accessed 15 May 2018

656 2getthere (2017b) Rivium GRT. https://www.2getthere.eu/projects/rivium-grt/. Accessed 15 May 2018

657 Alessandrini A (2016) CityMobil2 - Experiences and recommendations. Final report of the CityMobil2 project.
658   http://www.citymobil2.eu/en/upload/Deliverables/PU/CityMobil2%20booklet%20web%20final_17%2011
659   %202016.pdf. Accessed 15 May 2018

660 Alessandrini A, Cattivera A, Holguin C, Stam D (2014) CityMobil2: Challenges and Opportunities of Fully
661   Automated Mobility. In: Meyer G, Beiker S (eds) Road Vehicle Automation. Springer International
662   Publishing, Cham

663 Andersson J, Habibovic A, Klingegård M, Englund C, Malmsten-Lundgren, V (2017) Hello Human – can you
664   read my mind? ERICM News 109:37-38

665 Ba Y, Zhang W, Reimer B, Yang Y, Salvendy G (2015) The effect of communicational signals on drivers'
666   subjective appraisal and visual attention during interactive driving scenarios. Behaviour & Information
667   Technology 34(11):1107–1118. doi: 10.1080/0144929X.2015.1056547

668 Beggiato, M, Witzlack, C & Krems, JF (2017) The gentle automated vehicle. Influence of vehicle speed,
669   daytime and pedestrian's age on the expected moment of car braking as sign of cooperation. In: Goschke T,
670   Bolte A, Kirschbaum C (eds) TeaP 2017 - Abstracts of the 59th Conference of Experimental Psychology.
671   Pabst Science Publishers, Lengerich, pp 172–173

672 Björklund GM, Åberg L (2005) Driver behaviour in intersections: Formal and informal traffic rules.
673   Transportation Research Part F: Traffic Psychology and Behaviour 8(3):239–253. doi:
674   10.1016/j.trf.2005.04.006

675 Bjørnskau T (2017) The Zebra Crossing Game – Using game theory to explain a discrepancy between road user
676   behaviour and traffic rules. Safety Science 92:298–301. doi: 10.1016/j.ssci.2015.10.007

677 BMW (2016) Vision Next 100. https://www.bmwgroup.com/en/next100/brandvisions.html. Accessed 15 May
678   2018

679 Böckle, M-P, Pernestål Brenden, A., Klingegård, M, Habibovic, A, Bout, M (2017) SAV2P – Exploring the
680   Impact of an Interface for Shared Automated Vehicles on Pedestrians' Experience. Proceedings of the 9th
681   International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications
682   (AutomotiveUI '17), Association for Computing Machinery, pp 136-140. doi: 10.1145/3131726.3131765

683 Braun V, Clarke V (2006) Using thematic analysis in psychology. Qualitative Research in Psychology 3(2):77–
684   101. doi: 10.1191/1478088706qp063oa

685 Brown B, Laurier E (2017) The trouble with autopilots: Assisted and autonomous driving on the social road.
686   CHI 2017, May 6–11, 2017, Denver, CO, USA doi: 10.1145/3025453.3025462

687 Cacciabue PC, Carsten O, Vanderhaegen F (2014) Is there still a need for CTW? Cogn Tech Work (2014) 16:
688   311. doi 10.1007/s10111-014-0286-y

689 Ceunynck T de, Polders E, Daniels S, Hermans E, Brijs T, Wets G (2013) Road Safety Differences Between
690   Priority-Controlled Intersections and Right-Hand Priority Intersections. Transportation Research Record:
691   Journal of the Transportation Research Board 2365:39–48. doi: 10.3141/2365-06

692 Clamann, M, Aubert, M, & Cummings, ML (2016) Evaluation of Vehicle-to-Pedestrian Communication
693   Displays for Autonomous Vehicles. Transportation Research Board:1–12

694 Craid J, Hancock P (1994) The perception of arrival time for different oncoming vehicles at an intersection.
695   Ecological Psychology 6(2):83–109

696   Demiroz YI, Onelcin P, Alver Y (2015) Illegal road crossing behavior of pedestrians at overpass locations:

697   Factors affecting gap acceptance, crossing times and overpass use. Accident Analysis & Prevention 80:220–

698   228. doi: 10.1016/j.aap.2015.04.018

699   Dey D, Terken J (2017) Pedestrian Interaction with Vehicles: Roles of Explicit and

700   Implicit Communication. Proceedings of the Proceedings of the 9th International ACM Conference on

701   Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '17), Association for

702   Computing Machinery. doi: 10.1145/3131726.3131765

703   Emmenegger, C, Risto M, Bergen B, Norman D, Hollan J (2016) The Critical Importance of Standards for the

704   Communication Between Autonomous Vehicles and Humans. Poster presented at the Automated Vehicle

705   Symposium 2016, San Francisco

706   ERTRAC (2017) Automated driving roadmap. Report of the ERTRAC working group "Connectivity and

707   Automated Driving". http://www.ertrac.org/uploads/images/ERTRAC_Automated_Driving_2017.pdf.

708   Accessed 15 May 2018

709   Färber B (2016) Communication and Communication Problems Between Autonomous Vehicles and Human

710   Drivers. In: Maurer M, Gerdes JC, Lenz B, Winner H (eds) Autonomous Driving. Springer Berlin

711   Heidelberg, Berlin, Heidelberg, pp 125–144

712   Ford (2017) Ford, Virginia Tech go undercover to develop signals that enable autonomous vehicles to

713   communicate with people. https://media.ford.com/content/fordmedia/fna/us/en/news/2017/09/13/ford-

714   virginia-tech-autonomous-vehicle-human-testing.html. Accessed 15 May 2018

715   Fink G (2017) Toyota Concept-i: More Like Concept AI. http://www.caranddriver.com/news/toyota-concept-i-

716   photos-and-info-news. Accessed 15 May 2018

717   GATEway Project (2017) Driver responses to encountering automated vehicles in an urban environment. Project

718   report PPR807. https://gateway-project.org.uk/wp-content/uploads/2017/02/Driver-responses-to-

719   encountering-automated-vehicles-in-an-urban-environment-1.pdf. Accessed 29 August 2017

720   Guéguen N, Meineri S, Eyssartier C (2015) A pedestrian's stare and drivers' stopping behavior: A field

721   experiment at the pedestrian crossing. Safety Science 75:87–89. doi: 10.1016/j.ssci.2015.01.018

722   Hagenzieker MP, van der Kint, L, Vissers LK, van Schagen I, de Bruin, J., van Gent P, Commandeur J (2016)

723   Interactions between cyclists and automated vehicles: results of a photo experiment. In: Schwab A, Otte D,

724   Twisk D, Johanssen H, Pietrantoni L, Dozza M, Hair S de (eds) 5th International Cycling Safety

725   Conference- Book of Abstracts

726   Habibovic A, Andersson J, Nilsson M., Lundgren VM, Nilsson J (2016) Evaluating interactions with non-

727   existing automated vehicles: three Wizard of Oz approaches. In Proceedings of the *Intelligent Vehicles*

728   *Symposium (IV)*, Gothenburg, pp 32-37. doi: 10.1109/IVS.2016.7535360

729   Houtenbos M, Hagenzieker M, Wieringa P, Hale A (2004) The Role of Expectations in Interaction Behaviour

730   Between Car Drivers. In: International Conference on Traffic and Transport Psychology. Elsevier, pp 303–

731   314

732   Imbsweiler J, Deml B, Palyafári R, Puente León, F, Ries F (2017a) Cooperation behavior of road users in t-

733   intersections. In: Goschke T, Bolte A, Kirschbaum C (eds) TeaP 2017 - Abstracts of the 59th Conference of

734   Experimental Psychology. Pabst Science Publishers, Lengerich

735   Imbsweiler J, Palyafári R, Puente León, F, Deml B (2017b) Untersuchung des Entscheidungsverhaltens in

736   kooperativen Verkehrssituationen am Beispiel einer Engstelle. [Investigation of decision-making behaviorin
737   cooperative traffic situations using the example of a narrow passage] at – Automatisierungstechnik
738   65(7):477-488
739   Keferböck, F & Riener, A (2015) Strategies for Negotiation between Autonomous Vehicles and Pedestrians. In:
740   Weisbecker, A., Burmester, M. & Schmidt, A. (ed) Mensch und Computer 2015 – Workshopband., Berlin:
741   De Gruyter Oldenbourg., pp 525–532
742   Kitazaki, S, & Myhre, N J (2015) Effects of Non-Verbal Communication Cues on Decisions and Confidence of
743   Drivers at an Uncontrolled Intersection. In: Public Policy Center (ed) Proceedings of the 8th International
744   Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design
745   Klatt WK, Chesham A, Lobmaier JS (2016) Putting Up a Big Front: Car Design and Size Affect Road-Crossing
746   Behaviour. PLoS ONE 11(7):e0159455. doi: 10.1371/journal.pone.0159455
747   Lagström, T, & Malmsten Lundgren, V (2015) AVIP-Autonomous vehicles interaction with pedestrians: An
748   investigation of pedestrian-driver communication and development of a vehicle external interface. Master
749   Thesis, Chalmers University of Technology
750   Madigan R, Louw T, Dziennus M, Graindorge T, Ortega E, Graindorge M, Merat N (2016) Acceptance of
751   Automated Road Transport Systems (ARTS): An Adaptation of the UTAUT Model. Transportation
752   Research Procedia 14:2217–2226. doi: 10.1016/j.trpro.2016.05.237
753   Madigan R, Louw T, Wilbrink M, Schieben A, Merat N (2017) What influences the decision to use automated
754   public transport? Using UTAUT to understand public acceptance of automated road transport systems.
755   Transportation Research Part F: Traffic Psychology and Behaviour 50:55–64. doi:
756   10.1016/j.trf.2017.07.007
757   Malmsten Lundgren V, Habibovic A, Andersson J, Lagström, Nilsson M, Sirkka A, Fagerlönn J, Fredriksson C,
758   Krupenia S, Saluäär D (2016) Will There Be New Communication Needs When Introducing Automated
759   Vehicles to the Urban Context? In: Stanton NA, Landry S, Di Bucchianico G, Vallicelli A (eds) Advances
760   in Human Aspects of Transportation: Proceedings of the AHFE 2016 International Conference on Human
761   Factors in Transportation, Florida, USA
762   Mathieu J, Bootsma RJ, Berthelon C, Montagne G (2017) Judging arrival times of incoming traffic vehicles is
763   not a prerequisite for safely crossing an intersection: Differential effects of vehicle size and type in passive
764   judgment and active driving tasks. Acta Psychol (Amst) 173:1–12. doi: 10.1016/j.actpsy.2016.11.014
765   Merat N, Louw T, Madigan R, Dziennus M, Schieben A (in press) Communication between VRUs and fully
766   automated road transport systems: What's important? Accident Analysis & Prevention. doi:
767   10.1016/j.aap.2018.03.018
768   Mercedes Benz F015 - Luxury in motion. https://www.mercedes-benz.com/en/mercedes-
769   benz/innovation/research-vehicle-f-015-luxury-in-motion/. Accessed 15 May 2018
770   Millard-Ball A (2017) Pedestrians, Autonomous Vehicles, and Cities. Journal of Planning Education and
771   Research 82(2):0739456X1667567. doi: 10.1177/0739456X16675674
772   Mitsubishi Electric (2015) Mitsubishi Electric Introduces Road-illuminating Directional Indicators.
773   http://www.mitsubishielectric.com/news/2015/1023.html. Accessed 29 August 2017
774   Nissan IDS Concept: Nissan's vision for the future of EVs and autonomous driving. http://nissannews.com/en-
775   US/nissan/usa/releases/nissan-ids-concept-nissan-s-vision-for-the-future-of-evs-and-autonomous-driving.
776   Accessed 15 May 2018

777 Nordfjærn T, Şimşekoğlu Ö, Rundmo T (2014) Culture related to road traffic safety: A comparison of eight
778   countries using two conceptualizations of culture. Accident Analysis & Prevention 62:319–328. doi:
779   10.1016/j.aap.2013.10.018
780 Parkin J, Clark B, Clayton W, Ricci M, Parkhurst G (2017) Understanding interactions between autonomous
781   vehicles and other road users: A literature review, Technical University of the West of England.
782   http://eprints.uwe.ac.uk/29153. Accessed 15 May 2018
783 Portouli E, Nathanael D, Marmaras N (2014) Drivers' communicative interactions: on-road observations and
784   modelling for integration in future automation systems. Ergonomics 57(12):1795–1805. doi:
785   10.1080/00140139.2014.952349
786 Rasouli A, Kotseruba I, Tsotsos J K (2017) Agreeing to cross: How drivers and pedestrians communicate. In:
787   Proceedings of the 2017 IEEE Intelligent Vehicles Symposium (IV), pp 264–269
788 Ren Z, Jiang X, Wang W (2016) Analysis of the influence of pedestrians' eye contact on drivers' comfort
789   boundary during the crossing conflict. Procedia Engineering 137:399–406. doi:
790   10.1016/j.proeng.2016.01.274
791 Risto, M, Emmenegger, C, Vinkhuyzen, E, Cefkin, M, & Hollan, J (2017) Human-vehicle interface: The power
792   of vehicle movement gestures in human road user coordination. In: University of Iowa (ed) Proceedings of
793   the 9th International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle
794   Design
795 Rothenbücher D, Li J, Sirkin D, Mok B, Ju W (2016) Ghost driver: A field study investigating the interaction
796   between pedestrians and driverless vehicles. In: Proceedings of the 25th IEEE International Symposium on
797   Robot and Human Interactive Communication (RO-MAN), pp 795–802
798 Sadigh D, Sastry S, Seshia SA, Dragan AD (2016) Planning for Autonomous Cars that Leverages Effects on
799   Human Actions. In *Proceedings of the Robotics: Science and Systems Conference. doi:*
800   10.15607/RSS.2016.XII.029
801 Saunders S (2017) Local Motors & Deutsche Bahn Launch Six-Month Self-Driving Olli Vehicle Pilot Program
802   on Euref Campus in Berlin. https://3dprint.com/161739/deutsche-bahn-olli-pilot-program/. Accessed 15
803   May 2018Savigny, E V (1995) Autofahrerzeichen: Funktion, Systeme, Autonomie [Signs of
804   drivers: Function, systems, autonomy]. Zeitschrift für Semiotik(17(1-2)):105–128
805 Schneemann F, Gohl I (2016) Analyzing driver-pedestrian interaction at crosswalks: A contribution to
806   autonomous driving in urban environments. In: 2016 IEEE Intelligent Vehicles Symposium (IV), pp 38–43
807 Semcon (2017) Who sees you when the car drives itself? https://semcon.com/smilingcar/ Accessed 15 May
808   2018Shor RE (1964) Shared Patterns of Nonverbal Normative Expectations in Automobile Driving. The
809   Journal of Social Psychology 62(1):155–163. doi: 10.1080/00224545.1964.9919512
810 Society of Automotive Engineers [SAE] (2016) Taxonomy and Definitions for Terms Related to Driving
811   Automation Systems for On-Road Motor Vehicles (Standard No. J3016_201609). SAE International
812 Sucha M, Dostal D, Risser R (2017) Pedestrian-driver communication and decision strategies at marked
813   crossings. Accident Analysis & Prevention 102:41–50. doi: 10.1016/j.aap.2017.02.018
814 Urmson C, Mahon I, Dolgov D, Zhu J (2015) Pedestrian Notification (US9196164B1)
815 Vanderhaegen F, Chalmé S, Anceaux F, Millot P.(2006) Principles of cooperation and competition – Application
816   to car driver behavior analysis. Cogn Tech Work 8:183-192

817 Várhelyi A (1998) Drivers' speed behaviour at a zebra crossing: a case study. Accident Analysis & Prevention
818   30(6):731–743
819 Vissers LK, van der Kint, L, van Schagen I, Hagenzieker MP (2016) Safe interaction between cyclists,
820   pedestrians and automated vehicles: What do we know and what do we need to know?, Report of the
821   SWOV Institute for Road Safety Research. The Hague. https://www.swov.nl/publicatie/safe-interaction-
822   between-cyclists-pedestrians-and-automated-vehicles. Accessed 15 May 2018
823 Waymo (2017) Say hello to Waymo: what's next for Google's self-driving car project.
824   https://medium.com/waymo/say-hello-to-waymo-whats-next-for-google-s-self-driving-car-project-
825   b854578b24ee Accessed 15 May 2018
826 Zito GA, Cazzoli D, Scheffler L, Jäger M, Müri RM, Mosimann UP, Nyffeler T, Mast FW, Nef T (2015) Street
827   crossing behavior in younger and older pedestrians: an eye- and head-tracking study. BMC Geriatr 15:176.
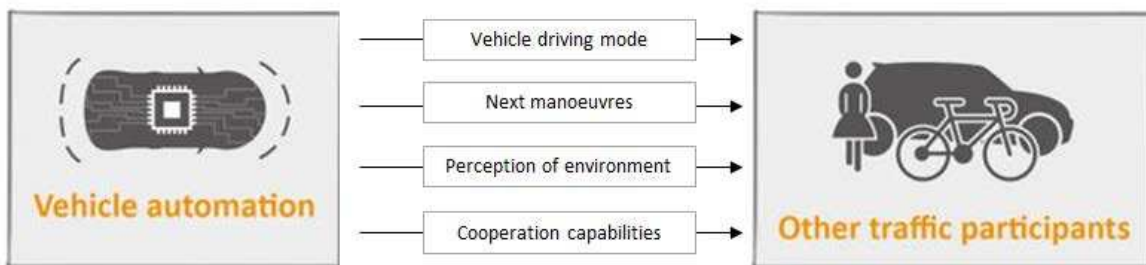828   doi: 10.1186/s12877-015-0175-0

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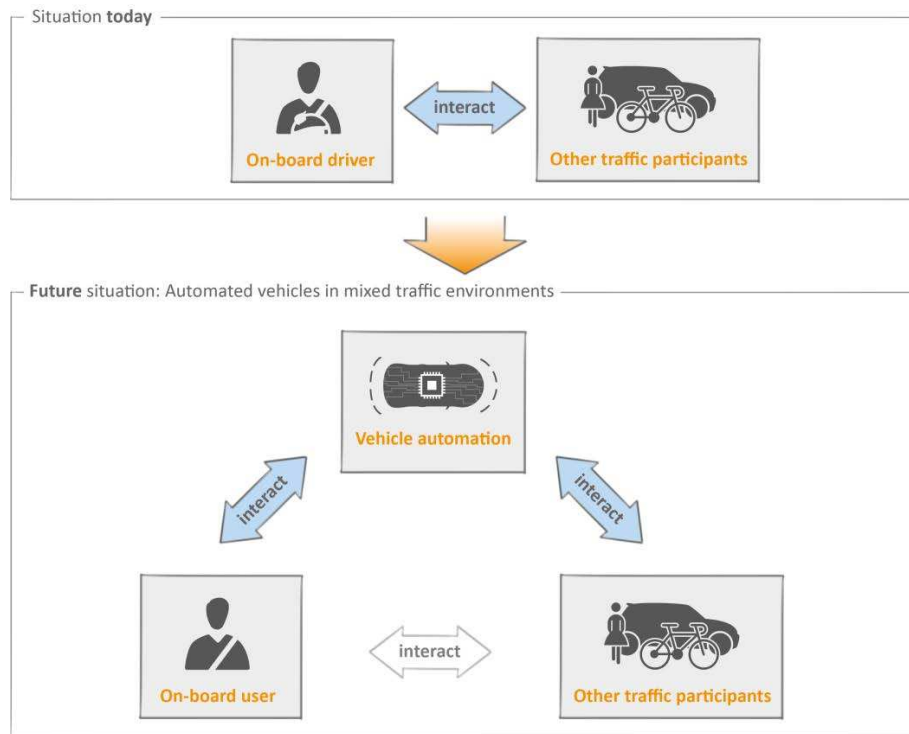
Figure 1: From today's situation of human-human interaction in mixed traffic environments towards a future situation with a triad of interaction between automated vehicles, other traffic participants and the on-board users (source: EU project interACT)

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

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845   **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	+	+	+	+

850   **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	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 text	symbols	light patterns & colour	HMI: acoustic 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	-	Reduces the number of potential conflicts when separated lanes are used	-	Expensive
	-	applicable in high-speed and low-speed scenarios	-	Lengthy implementation process
	-	dedicated tracks increase feeling of safety	-	Limits AV to specific areas
			-	Requires local or national government buy-in
Vehicle shape	-	AV can be recognised as clear sender of information	-	Manufacturer specific – not standardised
	-	applicable in high-speed and low-speed scenarios	-	No differentiation possible for vehicles with multiple automation levels
Vehicle behaviour	-	Similar to common interaction		
	-	AV can be recognised as clear sender of information	-	Cultural differences in expected vehicle behaviour – large variations that make it difficult to standardised
	-	applicable in high-speed and low-speed scenarios		
Visual HMI: text	-	Specific meaning can be transferred	-	Language skills necessary
	-	AV can be recognised as clear sender of information	-	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	-	No language skills necessary	-	Meaning of light patterns not intuitive
	-	AV can be recognised as clear sender of information	-	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	-	No language skills necessary	-	Meaning of symbols not always intuitive
	-	AV can be recognised as clear sender of information	-	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	-	Specific meaning can be transferred	-	Language skills necessary
	-	Other traffic participants do not need to look at the AV	-	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:	-	No language skills necessary	-	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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