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1 HMI Design in the Context of DMS and
2 Automation: Emerging Themes from an Expert
3 Workshop

4 Angus McKerral^{1*}, Megan D. Mulhall¹, Rafael C. Gonçalves²,
5 Ilse Harms³, Natasha Merat², Georgia Tuckwell¹, Shiyan Yang¹,
6 Kyle Wilson¹

7 ¹Seeing Machines Ltd, Canberra, Australia.

8 ²Institute for Transport Studies, University of Leeds, United Kingdom.

9 ³RDW, Netherlands Vehicle Authority, Netherlands.

10 *Corresponding author(s). E-mail(s):

11 Angus.McKerral@seeingmachines.com;

12 Contributing authors: Megan.Mulhall@seeingmachines.com;

13 r.goncalves@leeds.ac.uk; iharms@rdw.nl; n.merats@its.leeds.ac.uk;

14 Georgia.Tuckwell@cqumail.com; Shiyan.Yang@seeingmachines.com;

15 Kyle.Wilson@seeingmachines.com;

16 **Abstract**

17 **Objective.** This paper consolidates insights from an expert workshop and
18 presents overarching design concepts on how to effectively integrate driver
19 monitoring systems (DMS) into vehicle interfaces.

20 **Background** The safety potential of DMS hinges on effective integration with a
21 vehicle's human-machine interface (HMI), enabling a broader range of response
22 options offered by increasing vehicle autonomy. Integration design significantly
23 influences user experience, acceptance, and consequently, driver safety. Different
24 driver impairment states may require different HMI approaches due to varying
25 physical and behavioural features of driver states, requiring a HMI strategy that
26 is more nuanced and customised than what is typically seen in automotive HMI.

27 **Method** Workshop attendees at the 2023 Automotive-UI conference engaged
28 in structured brainstorming, identifying ideal HMI system responses, implemen-
29 tation strategies, and associated risks for the detection of impaired drivers.
30 Brainstorming occurred for two use cases (either distracted or drowsy); first in
31 the context of manual driving, followed by highly automated driving (SAE L3+).
32 **Results** Concepts included generic and state-specific responses, and level-of-
33 automation-specific and -agnostic intervention strategies. Notably, DMS-HMI
34 integration extended beyond simple alerts, with concepts addressing short-term
35 risk-mitigation and long-term behaviour-change as intended outcomes.
36 **Conclusion** These principles represent contemporary thinking which must
37 be tested and refined as the available technology develops, in turn enabling
38 additional adverse driver states to be addressed.
39 **Application** Design norms around DMS-HMI integration are yet to be estab-
40 lished. DMS-HMI integration will be critical to the user acceptance and safety
41 benefits of DMS, requiring a nuanced and considered approach.

42 **Keywords:** driver monitoring systems; drowsiness; distraction; human-machine
43 interface

44 1 Introduction

45 Driver-monitoring systems (DMS) are an increasingly common in-vehicle technology
46 that reduce the prevalence and risks associated with impaired driver states ([Fitzhar-
47 ris, Liu, Stephens, & Lenné, 2017](#)). Since 2022, the European Union’s General Safety
48 Regulation (GSR) mandates all new vehicle types employ driver drowsiness and atten-
49 tion warnings (DDAW; [Council of European Union, 2021](#)) and in July 2024 this was
50 extended to include advanced driver distraction warnings (ADDW).

51 Despite the increasing uptake of camera-based DMS, fully realising the poten-
52 tial safety benefits of the technology requires integration into the vehicle system as a
53 whole. Maximising DMS safety benefits requires a well-designed and research-based
54 human-machine interface (HMI) and seamless integration with other Advanced Driver
55 Assistance System (ADAS) features. Furthermore, drivers and passengers primarily
56 experience a DMS through the HMI, making effective HMI design critical to the user
57 experience and user acceptance alike. As yet, there is minimal guidance describing

58 how driver monitoring should be integrated within a vehicle. Both Euro NCAP pro-
59 tocols and GSR provide recommendations around minimum expectations of HMI for
60 DMS, including guidelines for different alert modalities in GSR, and requirements for
61 integration with ADAS features to achieve maximum points from Euro NCAP. Guide-
62 lines and standardisation are critical for ensuring a consistent experience, irrespective
63 of the vehicle model and manufacturer. In order for DMS to be effective, it must be
64 utilised consistently, and warnings acted upon (rather than ignored or deactivated)
65 by drivers. For a system to be accepted by the general population, perceived useful-
66 ness, ease of use and attitudes to system use are essential considerations for system
67 design (Davis, 1993). Even a well-designed DMS will likely be deactivated if the HMI
68 is poorly designed and drivers perceive alerts as a nuisance. Existing design guidelines
69 for HMI interactions (Saffer, 2013) warn system designers that inadequate or mistimed
70 communication by the system may compromise user experience, and that a resultant
71 unpleasant user experience may lead to driver misuse of the system (Parasuraman
72 & Riley, 1997). Specifically, automotive HMI design and evaluation guidelines (e.g.
73 Schömig et al., 2020) have proven useful for considering how best to communicate
74 system state, warnings and other vehicle functions within an increasingly automated
75 driving environment, and similar guides will be required to shape HMI alerting and
76 intervention strategies in response to the detection of impaired driver states. This
77 paper contributes to that aim by presenting the outcomes of an expert workshop ses-
78 sion (Mulhall, McKerral, et al., 2023) conducted at Automotive UI'23 (September) in
79 Ingolstadt, Germany, with a focus on specific driver states.

80 **1.1 Guidelines for HMI design**

81 Previous examples of design guidelines have been developed to assist with the devel-
82 opment of safe HMIs that address their distraction potential, including the national
83 highway transport safety administration's (NHTSA) own guidelines aimed at limiting

84 the distractability of in-vehicle technologies (NHTSA, 2013). Similarly, checklist-style
85 tools based on NHTSA recommendations offer a practical method for designers to
86 inform the development of in-vehicle HMIs (GDV, 2023). Within the extant litera-
87 ture, a taxonomic approach to approaching distraction-related design has considered
88 automation, task type (driving or non-driving related), and whether a task is driver-
89 or system initiated for its distraction effect (Donmez, Boyle, & Lee, 2003, 2008). He,
90 Kanaan, and Donmez (2019) revised this taxonomy in the specific context of highly
91 automated vehicles (defined by the authors as SAE L2-L4).

92 However, still absent is a consolidated set of principles for the integration of DMS
93 into this automotive environment, with specific work to consider integrated DMS-
94 HMI design noted as a gap in the extant literature (M. Wang et al., 2024). While
95 previous work often implicitly assumes the system’s capacity to detect driver state, the
96 present paper seeks to explicitly consider the capacity of DMS to detect specific driver
97 states as a dimension in defining the ideal system response, alongside the previously
98 considered dimensions of level of automation and distraction task-type. As He et
99 al. (2019) state, a challenge in implementing the authors’ proposed taxonomy for
100 automated vehicles lies in ”the feasibility of driver state detection technologies”. With
101 the requirement from multiple safety regulators to include increasingly sophisticated
102 driver monitoring technologies, it is important to reassess how these alerting strategies
103 should be integrated with the vehicle system in order to maximise the technology’s
104 safety potential.

105 **1.2 Generic alerts or state-specific responses?**

106 A key consideration for the question of HMI design is that of response specificity; the
107 extent to which alerts and other system responses are uniquely tailored to a given
108 state (Hecht et al., 2018; M. Wang et al., 2024). As the sophistication of available
109 DMS in contemporary vehicles increases, so too does the opportunity to implement

110 system responses that are specific to the detected impaired state, with the intention of
111 improving driver attentiveness or mitigating potential risk. In the preparation for this
112 workshop, the organisers selected specific driver states for discussion which reflected
113 current areas noted to be of interest for regulators ([Fredriksson, Lenné, van Montfort,
114 & Grover, 2021](#)). Selection of driver states for discussion also balanced the challenge
115 of alerting for states with significantly different antecedent conditions and differing
116 susceptibility to system intervention.

117 **1.2.1 Transient vs Non-transient states**

118 Transient impairment describes impaired states or behaviours that last for a short
119 period of time, over which a driver typically has a high degree of control over, and
120 can resolve immediately (e.g., distraction; [Euro NCAP, 2024](#)). Whereas non-transient
121 impairment refers to states which have a much longer duration of effect, and typically
122 cannot be immediately resolved by the driver (e.g., impairment due to drowsiness or
123 intoxication). Generally, drivers can comply with warnings for transient impairment
124 by immediately altering or correcting their behaviour. Conversely, compliance with
125 warnings for non-transient impairment may require the driver to stop driving as soon
126 as is practicably possible. For example, a driver becoming distracted by their phone
127 represents a transient state, whereby either through a salient warning or the driver's
128 own monitoring, their attention can be reoriented to the roadway. By contrast, a
129 drowsy driver may be made aware of their own fatigue, but neither the driver's own
130 effort nor an alert from the vehicle system is likely to meaningfully improve their
131 alertness in the short-term.

132 Importantly, it is unlikely that all driver states will fit neatly into a category
133 of 'transient' or 'non-transient', but will instead lie somewhere along a spectrum.
134 Nevertheless, for the present workshop distraction was chosen as an example of a
135 transient state, while drowsiness was chosen as an example of a non-transient state.

136 1.2.2 Distraction

137 Typical long-glance away (LGA) distraction events occur frequently in naturalistic
138 driving (Mulhall, Wilson, et al., 2023) and are defined as a glance away from the
139 roadway that exceeds a given duration threshold (Euro NCAP, 2022). Short multi-
140 glance distraction, also known as Visual Attention Time-Sharing (VATS), is a complex
141 distraction behaviour that involves drivers dividing their visual and cognitive attention
142 between driving and a secondary task such as using a mobile phone. The Euro NCAP
143 protocol defines VATS distraction as a cumulative 10s off-road gaze over a 30s window
144 (Euro NCAP, 2022). While data from simulator research has shown higher rates of
145 VATS events compared to LGA (Forster et al., 2024), naturalistic driving data has
146 shown the opposite trend (Mulhall, Wilson, et al., 2023). The difference in findings
147 may be attributed to the nature of the distraction tasks in either research paradigm;
148 Forster et al. (2024) instructed participants to engage in deliberately distracting tasks,
149 such as selecting a song from a playlist, or searching for a friend’s phone number. These
150 are realistic events however the design of instructing participants to engage in these
151 activities may increase the prevalence of alerts. In comparison, Mulhall, Wilson, et al.
152 (2023) investigated alert prevalence during naturalistic on-road driving, and indicated
153 substantially lower alert rates for both LGA and VATS events. The discrepancy in
154 alert prevalence between paradigms and testing environments underscores the need
155 for further research.

156 1.2.3 Drowsiness

157 Drowsiness is a state of extreme sleepiness, and driving while drowsy represents a
158 significantly increased risk of crashes (Lee et al., 2016; Tefft, 2018). Performance
159 impairments from drowsiness after 18.5 hours of wakefulness are equivalent to per-
160 formance impairments seen in drivers with a blood alcohol concentration of 0.05%
161 (Arnedt, Wilde, Munt, & MacLean, 2001; Dawson & Reid, 1997), the legal alcohol

162 limit in many jurisdictions. The inclusion of drowsiness monitoring systems is now
163 compulsory in much of Europe for new car types after the introduction of the GSR
164 DDAW ([Council of European Union, 2021](#)). However, a recent review demonstrated
165 that research thus far has focused on the development of sensors for monitoring drowsi-
166 ness, but has largely neglected the question of what are appropriate HMI responses
167 following detection ([Ayas, Donmez, & Tang, 2023](#)).

168 **1.3 System response across levels of automation**

169 Finally, the intervention initiated by a vehicle HMI, whether it be a generic alert or
170 a complete vehicle stop, will depend on the capabilities of the vehicle's (ADAS). At
171 SAE L0-L2 ([SAEJ3016, 2018](#)), possible interventions are likely to emphasise support-
172 ing driver action or behaviour change, with the possibility of system tuning, such as
173 increasing the responsiveness of automated lane-keeping systems (ALKS). At SAE L3+,
174 possible interventions begin to include complete control transitions and other more
175 advanced vehicle interventions.

176 The workshop described in the present paper is intended to consider a vehicle's
177 level of automation as a way of contextualising the range of alerting and mitigation
178 strategies available to vehicle designers for a given adverse driver state. As vehicle
179 systems become increasingly advanced, the range of strategies available to designers
180 increases, making once-speculated interventions (such as a safe-stop manoeuvre in
181 response to an impaired driver; [Bauder, Paula, Kujatko, & Schweiger, 2023](#)) a present
182 reality. Ultimately, the interaction between DMS detection capabilities, driver state,
183 and vehicle response will determine the efficacy of DMS ([Fredriksson et al., 2021](#)).
184 It is the aim of this paper to bring together current perspectives from the research
185 and design community on this topic collected during our workshop in order to further
186 maximise the benefits of DMS as a safety technology.

187 **2 Workshop Recap**

188 The workshop was proposed to bring together collaborators from across industry,
189 academia, policy makers, and other relevant stakeholders to participate in guided
190 discussion on the topic of HMI design for DMS in the context of automation. The
191 session was split in half, with organisers first presenting primer presentations on their
192 respective domains of expertise. These presentations covered:

- 193 1. an introduction to basic DMS concepts, such as methods of alerting through an
194 HMI, DMS-ADAS integration, and behavioural change across contexts and driver
195 states.
- 196 2. highly-automated driving, and DMS alerting in an automated context.
- 197 3. principles of HMI design for automotive use-cases.
- 198 4. regulatory considerations for the implementation of driver assistance systems, using
199 lane-keeping systems (LKS) as an example case.

200 The second half of the session progressed to the workshop activity and an overview
201 of the activity flow is presented in Figure 1. Participants nominated an impaired driv-
202 ing state that interested them, and were issued with instructions for a brainstorming
203 activity.

204 **2.1 Instructions to participants**

205 Each group was tasked with addressing the question of "*How should the system respond*
206 *given the detection of X state by the DMS?*". With regards to distraction, partici-
207 pants were asked to focus specifically on distraction in the form of visual-attention
208 time-sharing (VATS). The following descriptions were presented to participants to
209 contextualise each impairment state, and explain the activity structure, prior to
210 commencing brainstorming.

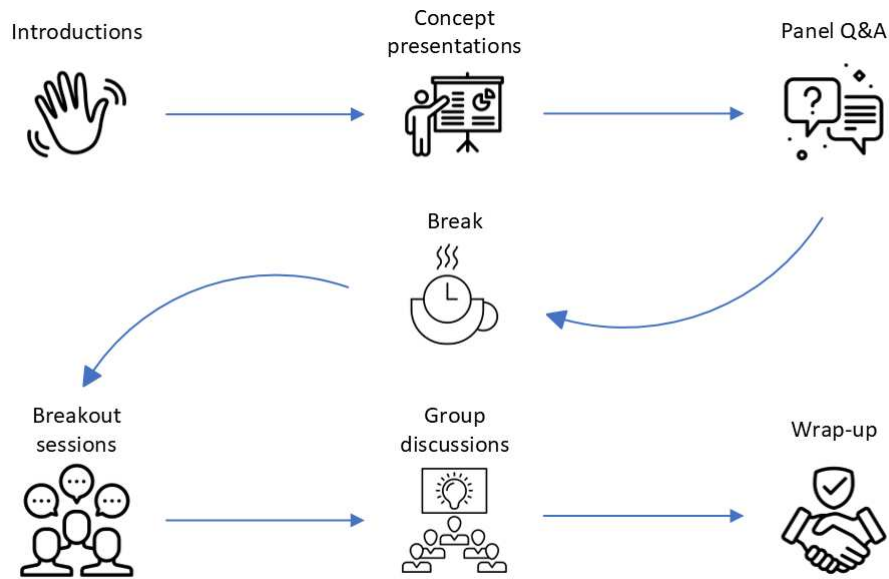


Fig. 1 Workshop activity flow

211 **2.1.1 What is drowsiness?**

212 The following description of drowsiness was presented to participants prior to com-
 213 mencing the workshop activity: A driver is displaying signs of extreme drowsiness.
 214 They are at risk of falling asleep at the wheel in the next ~30 minutes. Drowsiness can
 215 significantly impair driving performance and increases the risk of crashes, particularly
 216 lane departure crashes. Examples where a driver is likely to experience drowsiness
 217 include driving after staying awake all night, driving during the early hours of the
 218 morning and driving for an extended period without a rest break.

219 **2.1.2 What is VATS?**

220 The following description of distraction was presented to participants prior to com-
 221 mencing the workshop activity: Visual Attention Time Sharing (VATS) is a complex
 222 form of distraction behaviour where a driver is attempting to multi-task: drivers
 223 are dividing their visual and cognitive attention between driving and a secondary

224 task. Examples where VATS is common include while using a phone and extended
225 interaction with infotainment centres.

226 **2.1.3 Structured brainstorming**

227 The brainstorming activity used a 'Disney' approach which is an effective method
228 for generating highly creative ideas in parallel with realistic constraints, and where
229 brainstorming focused on 3 different steps (see [Tausch, Nußberger, & Hußmann, 2015](#),
230 for a detailed discussion). Step 1 was the 'dreamer' stage, where the focus was on
231 generating as many ideas as possible, while ignoring constraints and limitations. Step
232 2 of the brainstorming was the 'realist' stage, where the instructions were to focus on
233 ways to make ideas implementable. Finally, there was the 'critic' stage, where risks and
234 difficulties with implementations were identified. This approach focuses on generating
235 novel ideas initially, before grounding these ideas in reality to determine if an approach
236 is feasible, or desirable.

237 **2.2 Workshop Responses**

238 This research complied with Declaration of Helsinki and was approved by Seeing
239 Machines' review committee. No identifying links to the identities of individual par-
240 ticipants were retained; instead, only aggregated features of workshop participants
241 are reported. All participants were attendees of Automotive UI'23 and comprised
242 post-graduate research students, university-based academics, regulator or government-
243 based researchers, and industry-based researchers (working for automotive original
244 equipment manufacturers; OEMs). Within the VATS-distraction topic group, six par-
245 ticipants were post-graduate research students, three were university based academics,
246 one was employed by a government organisation or regulatory body, and three were
247 employed by OEMs. Within the drowsiness topic group, one participant was a post-
248 graduate research student, four were university based academics, three were employed
249 by a government organisation or regulatory body, and two were employed by OEMs.

250 The activity was designed to allow participants to repeat the exercise separately
251 assuming the driver-state of interest was detected in a manual and assisted driving
252 environments (SAE L0-L2), and a highly-automated driving environment (SAE L3+).
253 Not all groups completed the activity for both contexts, and as a result, there is not
254 necessarily the same level of detail for themes and resultant design principles derived
255 for each state. Where principles are clearly only applicable to one state or another,
256 this is noted. Further, although the activity was designed for participants to separately
257 discuss driving at different automation levels, the group ideation phase of the activity
258 in particular involved free-flowing conversation that often traversed concepts applica-
259 ble to multiple automation levels. As such, while each group was initially prompted
260 to begin discussions for their impairment state in the context of either manual or L3+
261 driving, the organisers opted to encourage free-flowing input. Ultimately, this trade-off
262 can be viewed as a necessary limitation of this form of qualitative workshop activity.

263 The workshop activity resulted in a variety of *response clusters*. In line with
264 the current approach, notes were allocated into 3 groups: Group 1) green notes
265 reflected an ideal system response; Group 2) yellow notes reflected realistic imple-
266 mentations; Group 3) red notes which reflected associated risks/barriers with a given
267 implementation (see Figure 2).

268 **2.3 Thematic Analysis of Participant Responses**

269 The analytic approach was considered data-informed and broadly inline with the con-
270 cept of reflexive thematic analysis, in which the role of the researcher as providing
271 active interpretation of the data is acknowledged (Braun & Clarke, 2006; Byrne, 2022).
272 Emergent themes were identified from responses and then structured within broader
273 frameworks.

274 Responses were clustered based on overlapping concepts and labelled by apparent
275 theme using the researcher’s own judgement. Clustering and labelling for each group

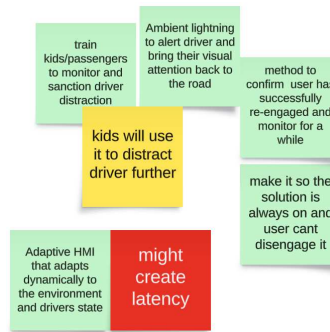


Fig. 2 An example of clustering concepts based on common themes. Green notes are generated in the 'dreamer' phase, yellow in the 'realist' and red in the 'critic' phase.

276 was repeated by a second expert rater and all themes were discussed in order to reach a
 277 consensus. Descriptions of themes are derived from response clusters and descriptions
 278 are augmented by conversations held with workshop participants (the authors acted
 279 as facilitators within groups).

280 3 Results & Discussion

281 This section will focus on interpreting the results of the workshop, and contextualis-
 282 ing responses within the extant literature. Results (themes) are highly interpreted by
 283 nature of the form of data, and it would be inappropriate to present these as objective
 284 data. Therefore, the emergent themes and discussion of them are presented concu-
 285 rrently. A summary list of key themes is presented in Table 1 according to the state
 286 detected. Note that themes are organised by the driver state that was referenced as a
 287 prompt to generate them, however each theme may apply across a range of additional
 288 states.

289 3.1 Distraction Themes

290 3.1.1 Scaling HMI to DMS Performance

291 A strong emphasis on DMS detection performance was noted as the foundation of any
 292 subsequent system response and overall system design. The HMI should be tailored

Driver state	Distraction	Drowsiness
<i>Theme</i>	Alerting modality	Alerting modality
	Gamification	Gamification
	Social accountability	Social accountability
	Digital guardian angel	Digital guardian angel
	Behaviour change	Behaviour change
	Scaling HMI to DMS performance	Negative reinforcement
	Context awareness/Adaptive HMI	Protecting/supporting driver performance
	Cabin control/enforceable system	Negative & Positive punishment
	Warning vs. reorienting alerts	Financial incentives

Table 1 Design themes derived from workshop attendee responses

293 to the accuracy of the DMS to detect distraction, as this has significant implications
294 for the response selected. It is inappropriate and unsafe to design a HMI with severe
295 vehicle interventions, such as an enforced safe stop procedure in response to a DMS
296 with a high false positive rate. A severe response to a false-positive event will elicit
297 distrust in the system and negate desired behavioural adaptation to alerts. Previous
298 research (Yu et al., 2017) has shown that system reliability has a strong effect on users’
299 trust in automated systems, which might affect the acceptance and usage of in-vehicle
300 technologies (Nordhoff et al., 2018). This argument is further supported by findings
301 in the field of aviation (Lyons et al., 2016) showing that the performance of pilot’s
302 supportive technology was a major factor influencing their usage. System responses
303 should be scaled against DMS performance to avoid frustrating drivers, leading to
304 ignored alerts even when an event is accurately detected.

305 **3.1.2 Context Awareness/Adaptive HMI**

306 Specific distraction contexts may require specific system responses, even when the
307 distraction behaviour is observably the same. Prototypes of context-aware interfaces
308 have been successfully developed within the vehicle context, and received positive
309 user feedback (Bellotti, Gloria, Montanari, Dosio, & Morreale, 2005). General design
310 recommendations for in-vehicle interfaces for both mobile apps (Apple Inc., 2024;
311 Google, 2024) and in-vehicle information systems (Harvey & Stanton, 2013; Stevens &

312 [Cynk, 2011](#)) have recommended that system designers account for contextual factors
313 (e.g. complexity of the driving environment), as it may affect a drivers capacity to
314 correctly perceive and comprehend the message. Distraction triggered by phone-use
315 may require alternative intervention strategies to distraction triggered by eating, or
316 even by excessive attention applied to driving related regions (e.g., rear/side mirrors).
317 Examples of other scenarios in which responses may need to be tailored include: having
318 children in the car; excessive mirror checking; eating while driving; mobile phone-use.

319 The ideal HMI is adaptable to both *the environment* and *a driver's state* and could
320 issue alerts via specific alerting modality combinations, frequencies, and intensities.
321 For example, 'a subtle alert could be appropriate for a driver who is showing early signs
322 of drowsiness, whereas a louder alert may be more suitable for a highly drowsy driver.
323 An HMI which responds uniformly to a detected state, irrespective of the context may
324 limit the range of applicable intervention strategies, whereas a system that is aware
325 of the external driving environment is better placed to make a decision about the
326 appropriateness of adjusting sensitivity of other ADAS features for instance.

327 **3.1.3 Cabin Control/Enforceable System**

328 The more the vehicle system is integrated with the broader cabin environment, the
329 greater the opportunity to forcibly prevent dangerous/distracting behaviour from com-
330 mencing or continuing by allowing the HMI to have control over non-vehicle interfaces.
331 Current Apple Car Play guidelines recommend drivers be prevented from performing
332 lengthy distracting tasks when using in-vehicle dashboards ([Apple Inc., 2019](#)). The
333 wide proliferation of in-cabin system integration in modern vehicles suggests that cabin
334 control systems might be a promising solution for DMS interfaces, however, general
335 design and usability guidelines support the idea that enforced restrictive behaviour
336 might have a detrimental effect on users' subjective experiences ([Kohler, 2022](#)). Inte-
337 grated systems would enable drivers to be temporarily locked out of system functions

338 (such as interactions with the IVIS) and/or connected devices. For example, the dis-
339 traction risk associated with mobile phone use can be mitigated by integrating personal
340 devices into the broader vehicle system in order to support the detection of distraction
341 as well as to directly deliver alerts via the device.

342 **3.1.4 Warning vs. Reorienting Alerts**

343 HMI alerts should be designed towards a desired behavioural outcome, such as *stop-*
344 *ping the behaviour* or *reorienting attention*. Workshop participants described an ideal
345 alerting strategy as one that achieves both outcomes by issuing alerts that are
346 informative (e.g. warning the driver that they are demonstrating distraction) and reori-
347 enting (actively re-directing attention back towards the roadway and/or safety-critical
348 attentional targets).

349 In the case of distraction (e.g. caused by phone use), the intention of the alert
350 is to stop the driver attending to their phone by providing a warning, ideally lead-
351 ing them to return their attention to the roadway. This form of alerting strategy is
352 widespread and has been shown to be effective in both commercial and consumer
353 automotive contexts (Ahlstrom, Kircher, & Kircher, 2013; Ferreira, Kokkinogenis, &
354 Couto, 2019). By contrast, reorienting alerts aim to redirect attention towards a spe-
355 cific safety critical location (e.g. Ho, Gray, and Spence (2013)) and previous research
356 has demonstrated that drivers in a highly-automated driving environment may react
357 faster and more accurately to directionally-aware takeover requests (Gruden, Tomažič,
358 Sodnik, & Jakus, 2022).

359 **3.2 Drowsiness Themes**

360 **3.2.1 Negative Reinforcement**

361 Negative reinforcement in this context refers to the removal of barriers (real or per-
362 ceived) that prevent drivers from stopping driving when they are drowsy. Intervention

363 strategies included facilitating *driver replacement* (passenger to take over, contact
364 a taxi/ride-sharing service, send backup driver), or to *suggest stopping at upcoming*
365 *cafes, shops*. These approaches are unlikely to be suitable in scenarios where critical
366 intervention is required, but may be effective in situations where the driver is showing
367 some signs of drowsiness and this state could be expected to worsen if they were to
368 continue driving. (Chen & Xie, 2014; Horne & Reyner, 1996).

369 **3.2.2 Protecting/Supporting Driver Performance**

370 In the event that severe drowsiness is detected and the driver is either unwilling or
371 unable to stop driving, it was recommended that an HMI should facilitate support-
372 ing strategies to protect the driver. Ideally, HMI and vehicle functionality would be
373 adapted to compensate for driver impairment, thereby mitigating crash risk until
374 the driver is willing/able to stop driving. Useful adaptations to system functions
375 could include: enhanced directions/navigation assistance; augmented reality display
376 to highlight lane position.

377 This approach relies heavily on advanced driver assistance systems, and recom-
378 mending such an approach without an established or consistent operational design
379 domain (ODD) for advanced systems presents a significant challenge. It is critical that
380 system adaptations do not simply foster “bad behaviour” and an over reliance on the
381 system where stopping driving is the preferred approach.

382 **3.2.3 Negative & Positive Punishment**

383 Negative punishment in the current context referred to the withdrawal of something
384 desirable in response to unsafe behaviour. Certain states (such as severe drowsiness
385 where a driver is displaying frequent microsleeps) may be considered sufficiently high-
386 risk as to warrant removing control of the driving task altogether, or limiting access
387 to convenience features. Concerns with this approach of limiting access to convenience
388 features included increasing boredom, which may in turn make drivers drowsier.

389 Positive punishment refers to concepts that involve the application of an aver-
390 sive stimulus in response to expressions of undesirable behaviour. With regards to
391 drowsiness, applied concepts often revolved around the notion of rousing the driver
392 when drowsiness is detected. A short-lasting but undesirable stimulus could help to
393 train the driver to avoid driving while drowsy in the future, and alerting the driver
394 in the moment. Examples include: seatbelt tightening (Nguyen, Jauregui, Dinges, et
395 al., 1998); changes to seating position. Whatever the stimulus, the link to the driver’s
396 state must be apparent to the driver to form an association. This requires the stim-
397 ulus to be sufficiently salient and temporally tied to behaviours associated with the
398 undesired state, however an excessively aversive stimulus risks drivers deactivating
399 the alert. All groups included an example of reprimanding strategies in their brain-
400 storming during the dreamer phase, however were typically critical of the idea being
401 actually implemented. The usage of punishment methods are likely to make drivers
402 inclined to reject the system, therefore defeating its purpose as an assistive tool.

403 **3.2.4 Financial Incentives**

404 The concept of financial incentives were often raised in abstract terms, with minimal
405 detail as to the specifics of implementation. General examples considered financial
406 punishment, such as issuing a fine in response to the detection of excessive drowsiness,
407 or financial reward, such as offering reductions in insurance premiums as a result of
408 safe driving practices. The practice of offering insurance premium discounts for drivers
409 with drowsiness DMS in their vehicle is already occurring on a small scale in the US
410 with heavy vehicle drivers, however further evidence is required to demonstrate the
411 efficacy of such approaches in a consumer automotive context (Soleymanian, Weinberg,
412 & Zhu, 2019)).

413 The concept of ‘financial incentives’ merits consideration as part of the broader
414 ecosystem that incorporates driver monitoring, however any approach is caveated by
415 legitimate concerns around data privacy (Dowthwaite, Cook, & Cox, 2024).

416 **3.3 Overarching Themes**

417 Overarching themes refer to those that emerged in reference to both distraction and
 418 drowsiness states, or were considered more broadly applicable to the question of DMS-
 419 HMI integration.

420 **3.3.1 Alerting Modality**

421 A number of considerations apply to the application of different alerting modalities
 422 when distraction is detected. These are presented in Table 2.

Modality	Distraction	Drowsiness
<i>Visual</i>	Ambient light. Reorienting indicators (where to look). Acknowledge limitations to symbol alerts (competing with visual component of VATS behaviour).	Blinking lights. Visual alerts considered less effective compared to haptic.
<i>Haptic</i>	Consider delivery via seat, steering wheel. Directional haptics to reorient attention to desired target. Use as a fallback when auditory and visual alerts have been unsuccessful.	Steering wheel response. Pitch-pulse vibration Seat-belt tightening/inducing deliberate seat discomfort.
<i>Audio</i>	Directional (towards roadway). Discrete (driver only). AI-informed - informative speech, voice models to which a given driver might be more receptive.	Loud alerting noise (arousing).
<i>Multi-modal</i>	Arguably best in most scenarios. Modality combinations can be used to scale up or down depending on severity.	

Table 2 Factors affecting the selection and implementation of alerting modalities.

423 Broadly applicable to all individual- and multi-modal alerts is the need to ensure
 424 drivers properly comprehend the alert, especially in the event of warnings in response
 425 to impaired states that - despite potentially representing a critical safety risk - may
 426 only occur infrequently. For example, drowsiness alerts should account for tired sight,
 427 and distraction alerts should not independently cause additional undue distraction, or

428 otherwise impair the desired driver response: improving and/or reorienting attention
429 towards the roadway.

430 **3.3.2 Gamification**

431 Gamification refers to the inclusion of game design elements in a non-gaming environ-
432 ment to improve usability and increase user participation and interest or satisfaction
433 (W. Wang, Gan, Wang, Lu, & Huang, 2022).

434 Gamifying driver behaviour was suggested in order to incentivise safe driving and
435 disincentive risky driving, and was a persistent theme across a range of different
436 detection scenarios. Gamification was often suggested by workshop participants as a
437 mechanism for targeting long-term behaviour change. Concepts included:

- 438 • A general points system, that enables leader-boards. Comparisons could be made
439 intra- or inter-individually.
- 440 • A mechanism for continuous coaching. Real-time or post-drive feedback could be
441 used to compare driver behaviour to expert/ideal behaviour, with greater similarity
442 drawing greater game rewards.

443 Driver "scores" may be compared both internally (a driver "beating" their previous
444 score) and externally (ranking highly compared to other drivers). However the risk of
445 introducing perverse incentives (e.g. pursuing a low score) must be considered.

446 **3.3.3 Social Accountability**

447 Participants suggested the use of social pressures, by way of comparison to a social
448 norm adhered to by other drivers, as an opportunity to influence drivers who would
449 otherwise continue to engage in risky behaviour (e.g. Rothe (1994)). Possible examples
450 of an HMI incorporating social comparison included: providing alerts to drivers such
451 as "*most people don't drive when they are this tired*"; external lights/signifiers that

452 mark a drowsy driver to indicate their impaired state to other road users; providing
453 drivers with statistics relevant to their current state indicating their relative crash risk.

454 **3.3.4 Digital Guardian Angel**

455 The concept of a digital agent that interacts with the driver was considered as an
456 advanced form of alerting modality, that could convey information to the driver about
457 their own state (e.g. being distracted) in more sophisticated, efficient and informative
458 ways, such as via two-way voice interaction. Additionally, a digital agent could provide
459 support to drowsy drivers in multiple ways, including encouraging stopping, support-
460 ing drivers to stay awake, or facilitating the use of convenience features to maintain
461 driver alertness.

462 Many of these ideas combined existing convenience features to promote safety.
463 Several studies have reported that regular communication between an automated sys-
464 tem and the driver - reporting the level of uncertainty of the system regarding their
465 surrounding environment (Beller, Heesen, & Vollrath, 2013; Ebnali, Fathi, Lamb, Pour-
466 falatoun, & Motamedi, 2020) or the system's perception of drivers' state (Gerber,
467 Schroeter, Johnson, & Rakotonirainy, 2021) - improved drivers' vigilance during auto-
468 mated drives. Consequently, this constant feedback approach may be beneficial, as it
469 may improve drivers' own self regulation of attention. However, secondary tasks (any-
470 thing outside of directly performing the driving task) could risk increasing a driver's
471 level of distraction, and this must be balanced against the opportunity for a greater
472 degree of information exchange between the driver and vehicle system.

473 **3.3.5 Behaviour change**

474 The consistent theme central to most, if not all concepts emerging from the workshop,
475 was the notion of promoting behaviour change through HMI alerts and interventions.
476 Depending on whether the detected state was transient (e.g., distraction) or non-
477 transient (e.g., drowsiness) in the short term, distinct strategies would be required.

478 Similarly, intervention strategies should distinguish between short- or long-term
479 behaviour change as the targeted outcome of a given HMI response.

480 Distraction behaviour was viewed as a largely voluntary state. Short-term strate-
481 gies included optimising alerts to quickly reorient attention to driving related regions
482 in order to minimise immediate risk, while long-term strategies emphasised training
483 driver behaviour by disincentivising distraction behaviour (imposing negative conse-
484 quences) and rewarding safe driving (incentivising an overall reduction in count and
485 severity of distraction events).

486 Drowsiness by comparison was not viewed as a voluntary state. Instead, interven-
487 tion strategies typically focus on the goal of stopping a drowsy driver from driving
488 (either to 'take a break' or find a substitute driver/mode of transport), as stopping the
489 drowsy person from driving was ultimately considered the safest option. Ideas target-
490 ing behaviour change included both short-term behaviour change (motivating drivers
491 to pull over as soon as possible when they are detected as being being drowsy) and
492 long-term behaviour change (encouraging reduction of drowsy driving incidence in the
493 long-term).

494 It is important to note that while the design themes for addressing distraction
495 tended to consider scenarios where a driver engages in voluntary distraction behaviour
496 (such as making a song selection on their infotainment system), it is likely that themes
497 identified for both voluntary distraction and (involuntary) drowsiness would apply
498 when alerting to involuntary distraction, such as when a driver's attention is captured
499 by a ringing phone. The present article categorises a number of emerging concepts
500 as "overarching themes" (section 3.3) which apply to both states, and as such should
501 also be considered for alerting to other adverse driver states that were out of scope
502 of this workshop. [Donmez et al. \(2003\)](#) directly call for future research to investigate
503 system functions intended to mitigate distraction that are tailored to the driver's
504 specific characteristics. Achieving the goal of driver-specific (and to a greater extent

505 driver-state specific) mitigation strategies requires close integration between accurate
506 and reliable DMS, and the range of system responses offered by increasing driving and
507 non-driving related system automation. The factor of timing introduced by (Donmez
508 et al., 2008) - accounting for *when* a mitigation strategy is applied in relation to the
509 driving task - in particular relates to the overarching concept of behaviour change
510 raised in the present paper. It is not sufficient to consider only the acute mitigation of
511 a given behaviour, but rather alerts should consider how they affect a driver both pre-,
512 peri-, and post-drive such that the incidence of an adverse state is, ideally, reduced.

513 4 Conclusion

514 Strong engagement from attendees showed that extensive thinking is already taking
515 place on the topic of DMS-HMI design. It is timely to begin bringing these perspectives
516 together, with the longer-term goal of establishing design norms that aim to maximise
517 the safety potential and acceptance of driver monitoring just as the technology is
518 becoming ubiquitous in modern vehicles. This paper presents a set of design themes
519 which were compiled in consultation with the authors, reflecting perspectives from
520 a range of academic and industry stakeholders. In doing so, these themes present a
521 background for the future development of DMS-HMI integration design norms that are
522 specific to automotive design in the context of advancing driver monitoring technology.

523 Two immediate applications for this form of data generation are regulatory and
524 consumer advocacy bodies (such as NHTSA, NCAP), and automotive manufacturers.
525 Existing guidelines from regulators (NHTSA, 2013) would benefit from consideration
526 of additional specific states, as well as the inclusion of generic norms useful in designing
527 for driver impairment of different or indeterminate states. Importantly, the alerting
528 and intervention strategies should themselves be developed with specific consideration
529 of the capabilities of a given DMS (in line with the recommendation to scale HMI
530 to DMS performance; section 3.1.1). The greater the fidelity of the detection system,

531 the more specialised the response strategy can be. For example, steering-only DMS is
532 unable to assess driver engagement while advanced driver assistance systems are active
533 (such as lane-keeping assist), as lateral control is shared, limiting the required input
534 from the driver to the wheel, and in turn limiting the efficacy of the system ([National
535 Transportation Safety Board, 2020](#)). Camera-based systems by contrast do not rely
536 on physical input, and an integrated solution that incorporates multiple sensing paths
537 may in fact offer the highest-fidelity solution ([Egelja & Pavkovic, 2024](#)).

538 Response-themes reflected both state-specific and generic approaches to alerting
539 styles and behaviour change, with an emphasis on enacting a multi-modal system-
540 wide approach. Key differences between responses to either drowsiness or distraction
541 detection appeared to stem from the agency of the driver in enacting the detected
542 behaviour; that is, drowsiness is a non-voluntary state and as such HMI design should
543 promote drivers to stop driving, whereas distraction is typically a voluntary behaviour
544 and alerting strategies should focus on stopping the behaviour and reorienting atten-
545 tion to the roadway. Interpreting the output holistically, it is important to reiterate
546 three key points:

- 547 1. DMS-HMI implementations must consider both short-term mitigation of the
548 detected adverse state, and long-term behavioural change, in order to prevent/re-
549 duce the frequency of future events.
- 550 2. Alerting strategies must go beyond providing a generic alert in response to a
551 detected complex adverse state. As vehicle automation increases, there is a clear
552 opportunity to make use of advanced system capabilities to apply increasingly
553 sophisticated interventions in responses to driver impairment.
- 554 3. Optimal short- and long- term strategies will vary depending on DMS-detected
555 state, and there is a need to establish clear guidelines that are both supported by
556 research and practical for manufacturers to implement.

557 The themes emerging from the workshop and discussed in this paper are by no
558 means intended as the final word on DMS-HMI design, and in some cases may not
559 prove effective or practical in an applied context. In describing each concept, the
560 authors have made every effort to reflect the intent behind discussions that took
561 place during the workshop session, however this does not necessarily constitute an
562 endorsement for a given theme to be applied. The brainstorming activity was intended
563 to allow participants to explore ideas rather than produce conclusive evidence in favour
564 of a given approach to alerts. This is ultimately both an aim and a limitation of
565 conducting a workshop in this manner.

566 Finally, while this paper focuses on detecting distraction and drowsiness, DMS-
567 HMI integrated design should also consider impairments from other adverse states such
568 as drug and alcohol intoxication ([Hayley et al., 2021](#)), sudden sickness ([Fredriksson et
569 al., 2021](#)), and a variety of other driver states for which DMS can enable driver impair-
570 ment mitigation strategies. Similar workshops in the future would ideally address a
571 broader range of adverse states, as the possible range of system responses to a given
572 adverse state is likely to differ substantially based on the findings of the present paper
573 (e.g. a re-orienting alert may be less effective for an intoxicated driver compared to a
574 distracted driver, whereas designing for long-term behaviour change is likely to be rel-
575 evant across a wide variety of adverse states). Additional design principles will likely
576 be needed for these states, and those presented here serve as a starting point. The
577 process of continuous evaluation and refinement are crucial in the ongoing pursuit of
578 ever-safer automotive design.

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