International Co-operation on Theories and Concepts in Traffic Safety

Rearward Countdown Timers as External HMIs on Highly Automated Shuttle Buses

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The use of highly automated shuttle buses (HASBs; SAE Level 4) represents a promising solution for ensuring broad access to flexible, safe, and sustainable mobility in the future. For example, HASBs could be deployed to supplement the current public transport system to cover the first or last mile (Beiker, 2016). However, for implementation, the number of bus stops would have to be expanded to include many decentralised, most likely on-demand, stops at the curb. When a HASB stops at a curbside stop, mainly two groups of road users interact directly with it: potential passengers who want to board the HASB and (motorised) traffic behind it, which either can overtake the HASB or is required to wait for its departure. To signal a continuation of the journey, conventional buses currently use established signals at bus stops, such as the left turn indicator and (the extinguishing of) the brake lights. However, these signals are merely used immediately before departure, which may not be sufficient for the time-critical assessment of the following traffic to decide whether it is feasible to overtake the HASB comfortably and safely. This period of only a few seconds, in which the departure of the HASB would be announced by the onset of the left turn indicator, is comparable to the dilemma zone, in which drivers have difficulty deciding whether to stop or continue when the traffic light changes from 'green' to 'yellow' (Moore & Hurwitz, 2013). At traffic lights, it has been shown that digital countdown timers (CDTs) increase the probability of drivers making comfortable stops in the *dilemma zone* (e.g., Islam et al., 2017). Hence, using CDTs at the rear of HASBs may also be beneficial in indicating the departure of HASBs more transparently, which could increase comfort for following traffic and overall road safety. In addition, it was reported that CDTs installed at traffic lights help cyclists adjust their speed accordingly (Nygårdhs, 2021). Similarly, CDTs at the rear of HASBs could assist approaching passengers in deciding whether or how comfortably they can reach a HASB. If the remaining time until the HASB's departure is recognisable from a distance, they can probably choose a more appropriate walking speed.

For both following traffic and approaching passengers, likely, a more transparent announcement of the forthcoming HASB's manoeuvre (i.e. its departure) by a CDT would increase predictability and thus improve levels 2 and 3 of situation awareness, i.e. comprehension of the current and anticipation of the future traffic situation (Endsley, 1995). To the authors' knowledge, using CDTs as external HMIs (eHMIs) to indicate a HASB's departure to surrounding road users, at least on the rear of HASBs, depicts a novel approach towards eHMIs. It has already been shown that eHMIs as additional light signals (e.g., light bands or displays of icons) that explicitly indicate the intended manoeuvres of HASBs improve the interaction with HASBs (Böckle et al., 2017; Hub et al., 2023). Moreover, information about forthcoming manoeuvres was identified as a fundamental communication need for interaction with automated vehicles (Schieben et al., 2019).

To gain first insights into the potential of CDTs to signal a HASB's prospective departure from a curbside stop, an online study ($N = 148$) based on repeated measurements with video sequences was conducted. At the beginning of each video, the HASB stopped at the curb and departed from the stop in the course of the video. As independent variables, the participants' *interaction perspective* ('following car' or 'boarding passenger', each approached the HASB from behind) and the *eHMI design* ('no CDT' as baseline condition comprising the currently established signals of the left turn indicator and the vehicle's braking lights, 'CDT with accompanied icon', or 'CDT with accompanied text') were applied (Figure 1). The digital CDT display was updated with a frequency of 1 Hz throughout. The duration of the HASB stop was kept constant for both interaction perspectives. Participants evaluated the eHMIs with questionnaires, such as *understanding/predictability* as a dimension of trust in automation (Körber, 2019) and *acceptance* (Van Der Laan et al., 1997).

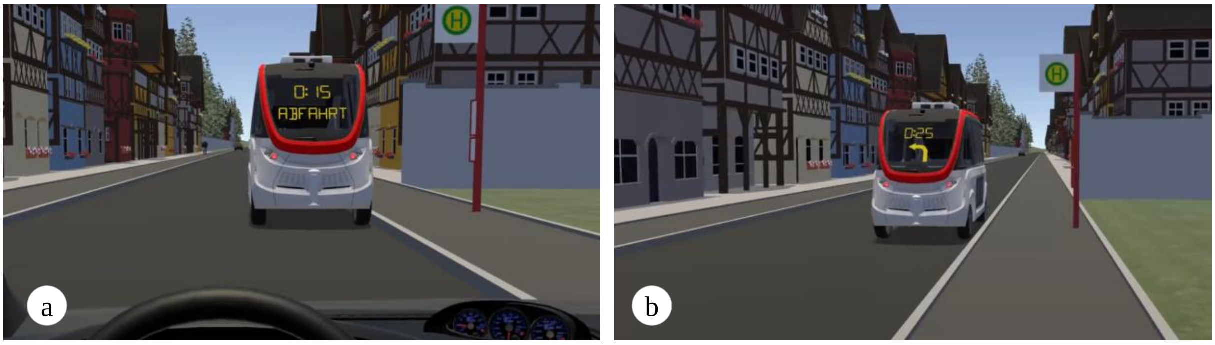

Figure 1: Example screenshots of the video material, showing (a) the interaction perspective of a following car with the eHMI design 'CDT with accompanied text', and (b) the interaction perspective of a boarding passenger with the eHMI design 'CDT with accompanied icon'.

The ANOVA of the 2x3 within-subject design revealed in terms of ratings on *understanding/predictability* of the HASB's departure a significant main effect for *eHMI design*, $F(1.59, 233.96) = 430.73$, $p < .001$, $\eta_p^2 = .746$. The large effect size mainly resulted from the significantly higher ratings of both conditions including the CDT than the 'no CDT' condition. In addition, 'CDT with accompanied text' was rated significantly higher than 'CDT with accompanied icon'. These findings were determined for the interaction perspective of 'following car' and 'boarding passenger'. Nevertheless, a significant interaction effect was found, $F(1.64, 240.46) = 14.23$, $p < .001$, $\eta_p^2 = .088$, since the baseline condition with 'no CDT' was rated significantly lower from the 'boarding passenger' perspective. Similar findings resulted for *acceptance* of the CDTs. All conditions that included a CDT were highly *accepted*, depicting scores above 1.0, based on the underlying rating scale ranging from –2 to +2 (Van Der Laan et al., 1997). Overall, the results support a prospective implementation of CDT eHMIs on HASBs. Lower ratings of the baseline condition for the 'boarding passenger' perspective might suggest a higher need for additional eHMIs in this context. In any case, the technical realisation appears feasible since exact parameters, such as the time until the continuation of a journey, may be determined precisely by a HASB system. Future research could investigate this topic further and conduct studies with higher external validity, such as test track studies.

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