Evaluating Highly Automated Trucks as Signaling Lights

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ABSTRACT

Automated vehicles will change the trucking industry as human drivers become more absent. In crossing scenarios, external communication concepts are already evaluated to resolve potential issues. However, automated delivery poses unique communication problems. One specific situation is the delivery to the curb with the truck remaining partially on the street, blocking sidewalks. Here, pedestrians have to walk past the vehicle with reduced sight, resulting in safety issues. To address this, we conducted a literature survey revealing the lack of addressing external communication of automated vehicles in situations other than crossings. Afterwards, a study in Virtual Reality (N=20) revealed the potential of such communication. While the visualization (e.g., arrows or text) of whether it is safe to walk past the truck only played a minor part, the information of being able to safely walk past was highly appreciated. This shows that external communication concepts carry great potential besides simple crossing scenarios.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; *Haptic devices*; User studies.

KEYWORDS

External communication; construction site; heavy machinery.

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1 INTRODUCTION

Automated vehicles (AVs) are expected to radically change the trucking industry [28]. Increased fuel economy and less need for truck drivers will lower the cost of delivery [28, 57].

There are scenarios in which a truck has to remain partially on the street to deliver [14]. A highly automated truck encountering such a scenario would, therefore, block the passage both for car drivers and pedestrians. With a potentially missing human driver in the future, the highly automated truck should substitute at least some of the communication with, for example, pedestrians. For the described scenario, it is difficult for pedestrians to assess whether it is safe to walk past the trucks due to its size. The Scania AXL, Scania's first prototype for mines [64], is equipped with a LED strip indicating awareness of objects around it. However, other forms of external communication are unexplored.

We present findings of a study simulating the described situation in virtual reality (VR; N=20). A pedestrian wants to walk past a highly automated truck standing halfway on the street. Results show that a highly automated truck can function as a "moving signaling light" for pedestrians, i.e., communicating to the pedestrian whether the street is blocked with oncoming vehicles. Participants clearly favored explicit visualized communication of the state of the street over awareness visualization. The visualization itself seemed not to be important (arrow, text, zebra).

This work also shows that AVs with external communication concepts can be useful in a wider spectrum of applications besides aiding in crossing scenarios (e.g., [19, 52]). While explicit communication was favored against awareness communication, juridical issues could prevent such application. Warnings issued could still aid in many situations.

2 BACKGROUND

This work evaluates how to improve the safety of pedestrians trying to walk past a standing highly automated truck via external communication while staying on the same side of the road. Therefore, an overview is given over previously presented external communication concepts also called external Human Machine Interfaces (eHMIs).

As we present a novel concept for highly automated trucks to communicate with pedestrians that do not want to cross the street, we also present an analysis on the current state-of-the-art scenarios for the evaluation of such eHMIs based on the generic scenarios (orthogonal, frontal, merging) defined by Kaß et al. [42] additionally divided by the factor *presence of a crosswalk*. An in-depth analysis of external communication concepts in academia showed that such scenarios have not yet been addressed.

2.1 External Communication of Autonomous Vehicles

Today, there are still ongoing discussions about the need for external communication of AVs [58]. However, various studies have shown benefits of the introduction of such concepts for people with visual impairments [19] and trust towards AVs in crossing decisions [50]. Issues such as overtrust were also shown [36].

Various external communication modalities have been evaluated. This includes displays [30], LED strips [30, 51], projections [2, 60] auditory [19] or tactile cues [19, 53] as well as combinations thereof [53]. Concepts have been grouped by used modality [53] or complexity [50]. Löcken et al. [50] compared 6 of these concepts. The concept *Smart Road* (based on work by Umbrellium [54]) was rated best in the relatively simple scenario. Colley et al. [19, 20] categorized the concepts based on the used modality. As construction sites tend to be noisy [41], according to the design space presented by Colley and Rukzio [17, 18], using visual clues seems to be most promising approach in the presence of a construction site.

2.2 Analysis of Evaluated Scenarios in the Context of External Communication of Autonomous Vehicles

The publications analyzed by Colley et al. [19] and Löcken et al. [50] were used for the analysis. Additionally, we queried the *AutomotiveUI* in the ACM Digital Library for eHMIs being the premier forums for automotive research (search query: `"query": AllField:("eHMI" OR "external communication") "filter": Conference Collections: AutomotiveUI: Automotive User Interfaces and Interactive Vehicular Applications`). A sample of **46** publications was collected of which **34** presented a study on eHMIs. The work by Rettenmaier et al. [62] was excluded as this work addresses eHMIs for the communication with other car drivers instead of communicating with pedestrians, leaving a sample of **33** publications (see Table 1).

scenario definition [42]	Crosswalk present	**number of publications** + [references]
Orthogonal	no	**17**: [2, 9, 13, 15, 19, 22, 26, 33, 36, 43, 50, 51, 53, 65, 73, 74, 76]
Orthogonal	yes	**13**: [5, 10, 12, 15, 23–25, 31, 39, 49, 52, 60, 72]
Frontal	no & yes	**0**
Merging	no & yes	**0**
Not specified or unclear	n.a.	**4**: [48, 55, 56, 66]
combined		**33** ([15]: with and without crosswalk)

Table 1: Categorization of publications based on the scenario definition and the presence of a crosswalk.

The analysis shows that most evaluation scenarios target an orthogonal (e.g., pedestrian stands at the curb) setup, i.e., being a crossing scenario. Frontal scenarios (i.e., the pedestrian is in front of an AV) as defined by Kaß et al. [42] are non-existent. Merging scenarios such as a bicycle merging with an AV are also absent. Our scenario falls into the category *frontal* as the pedestrian is directly walking towards the highly automated truck and its eHMI (see Figure 1), therefore, being, to the best of our knowledge, the first evaluation of an eHMI in this kind of scenario. The current ISO technical report on eHMIs [1] promotes the usage of intention-based messages (e.g., *stopping*) instead of command type messages (e.g., *Cross* [53]) to avoid liability issues. For an AV to be able to "allow" a pedestrian to cross, the AV has to know whether a vehicle is approaching from the oncoming street. For example, on a two-way road, if the AV wants to signal the pedestrian that it is safe to cross, knowledge about the status of the other lane is necessary. This was however, neglected in current scenarios. For our approach, we assume the highly automated truck to have sensors allowing it to perceive its environment for at least 300 m (Waymo claims to "identify [...] stop signs greater than 500 meters away" [40]). This allows the highly automated truck to *predict* an oncoming street to be free for ≈ 22 s when no vehicle (with a velocity of oncoming traffic of 50 km/h as a speed limit within cities in Germany; see §3 STVO [67]) is recognized.

3 STUDY

To evaluate concepts regarding the communication of a highly automated truck with other pedestrians when blocking a street or a sidewalk, we designed and conducted a within-subject study (*N*=20) in VR.

3.1 Apparatus

In our scenario, the participant stands on a sidewalk. A highly automated truck backs in a construction site. The entrance is ≈ 2 m from the participant. The highly automated truck comes to a halt but is still partially on the road (see Figure 1). The evaluated concepts (see Figure 3) are then displayed depending on the oncoming traffic. In half of the conditions, *no (oncoming) traffic* (see Figure 1) was simulated, in the other half *oncoming traffic* was simulated which eventually ceased. Due to space and tracking constraints, we added a gain factor in the straight forward and sideways (not height) axis. A gain of 2.0 (meaning 1 m in reality equals 2 m in VR) was employed as done by Colley et al. [19]. The scenery is depicted in Figure 1. To indicate where the sidewalk ends, we used quarter rounds as shown in Figure 2.

3.2 Evaluated Concepts

The evaluated concepts are shown in Figure 3. As this is a previously unexplored setup, we used tested external communication concepts from use cases such as pedestrian crossing (e.g., [19, 36, 52]) as well as concepts from industry [4, 64] and adapted the concept to this use case, i.e., we had to design the interface for the street being blocked (see even-numbered pictures in Figure 3). Additionally, we implemented novel concepts. According to the design space proposed by Colley and Rukzio [17, 18], *visual* and *auditory* modalities were used.

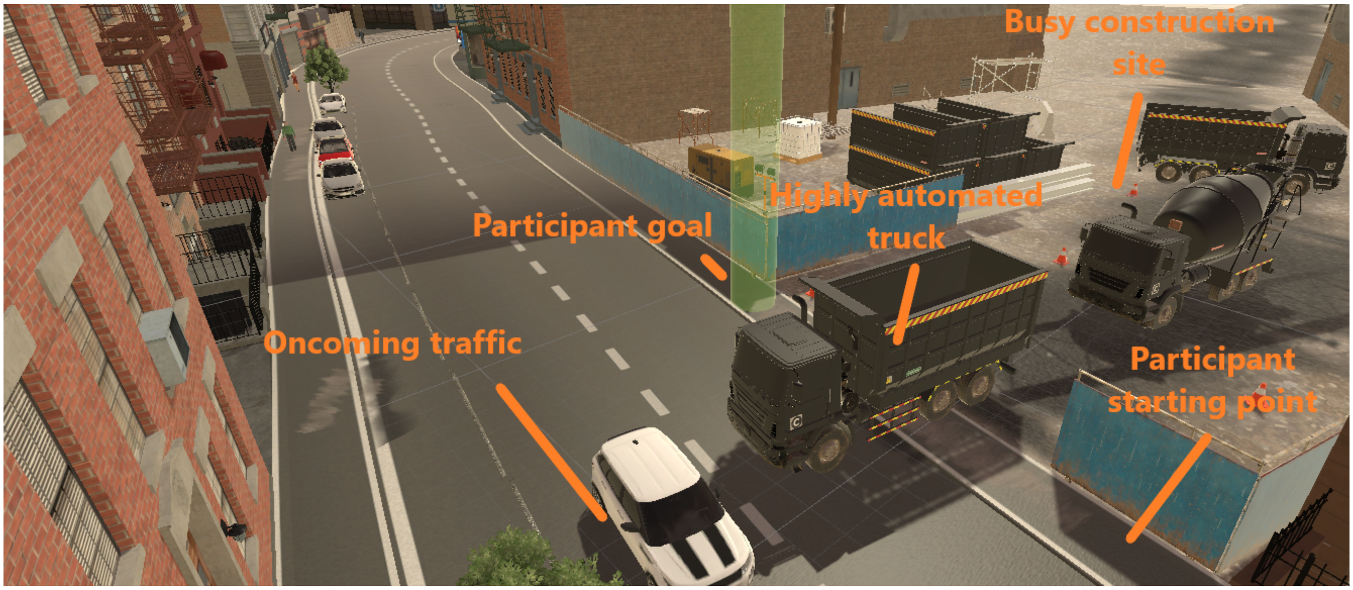

Figure 1: Overview of the study scenario.

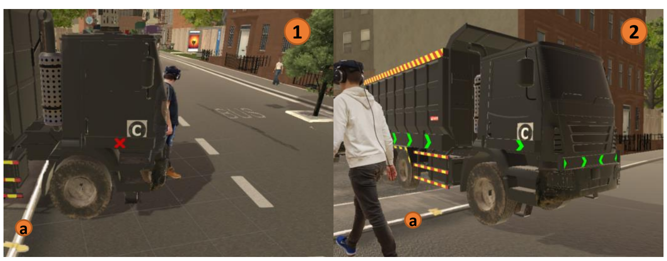

Figure 2: Two participants with an overlay of the scene. (1) shows a participant looking for traffic while (2) shows a different participant that already walked past the truck. (a) highlights fixated quarter rounds.

Baseline: No explicit communication is given (see Figure 3 (1) and (2)).

Auditory: The highly automated truck played repeatedly with frequency of 0.33 Hz (ergo every 3 s) to allow for the recognition of other relevant auditory information [19]) "free" or "busy" (see Figure 3 (3) and (4)). While construction sites tend to be noisy [41], people with vision impairments could still receive aid via such a concept [19].

Text: A display showed the text "free" in green or "busy" in red (see Figure 3 (5) and (6; text was shown to be least ambiguous [11, 23, 31, 52, 53])).

Arrows: A moving green arrow ← or a red X signalized whether it is safe to cross (see Figure 3 (7) and (8); resembling a more sophisticated version of an LED signal [30, 51]). As we gave explanations for every concept, no participant mistakenly thought the arrows show the intention to start driving.

Zebra: A zebra crossing in turquoise (being a promising colour for AVs [71]) was displayed on the street when the street was free (see Figure 3 (9) and (10); as proposed by Daimler [4] and investigated by Löcken et al. [50]).

Recognition: A display going round the highly automated truck lighted up at the recognized position of the participant in varying colors: green towards the front of the highly automated truck, yellow in the middle and red in the back, suggesting that it is safer to cross in front (see Figure 3 (a), (b), and (c)). This resembles the state of the art in the industry [4, 64] with an additional message layer via color-coding.

3.3 Procedure

The relevant parameters for the situation are the occurrence of traffic and the external communication concept. As we were interested in how well participants understand, trust, and like such systems, the study was guided by the research question:

> *What impact do the variables "traffic" and "communication concept" have on pedestrians in terms of (1) dominance, (2) cognitive load, (3) trust, (4) preference, (5) confidence, and (6) appropriateness?*

Dominance was also included as "control over the situation" [7] to assess whether participants feel patronized.

It was designed as a within-subjects, repeated measures experiment with 2 (*vehicle presence*: present or not) × 6 (*external communication concepts*: none, visual *Arrows*, visual *Text*, visual *Recognition*, visual *Zebra*, *Auditory*) conditions.

Every session started with an introduction, the signing of the consent form, and a demographic questionnaire. Afterwards, the 2 *Baseline* conditions followed by the remaining 10 conditions in counterbalanced order were presented. Therefore, the *Baseline* was shown first for all participants to avoid priming them to walk in

Figure 3: Conditions of the study. 1 - 10 represent the respective conditions (even numbers indicate conditions *with* traffic). a, b, and c show the *Recognition* concept in which the position of the pedestrian is visualized combined with a color indicator suggesting the way to walk (green).

front of the truck via the interfaces. This was done to study the effect of interfaces on the decision to walk past the truck in the front or the back. Participants were told to reach their goal (a position indicated by a green waypoint; see Figure 1). Before every condition, a written explanation was given. Intentionally, the simulation was designed that it was possible to walk behind the truck. Depending on the condition, oncoming traffic was simulated. Randomly, between one and three vehicles drove past the highly automated truck before a gap emerged for the participant to walk past. After all conditions, participants gave general feedback. A session lasted ≈ 40 min. Participants were compensated with € 8.

3.4 Measurements

Objective dependent variables: The position and gaze direction of the participant were logged with 10 Hz. Additionally, the time needed for executing the task (reaching the waypoint) was logged.

Subjective dependent variables: After each run, we measured affective state with the self-assessment manikin (SAM) [6] on a 7-point semantic scale, cognitive load with the raw NASA-TLX [35] on a 20-point scale, and the subscales *Predictability/Understanding* and *Trust in Automation* of the *Trust in Automation questionnaire* by Körber [44]. Participants were additionally asked on individual 7-point Likert scales to what degree they felt safe, whether the highly automated truck seemed trustworthy, and if the communication was comprehensible and unambiguous.

After all sessions, participants rated their preferences regarding the systems from greatest (*ranking = 1*) to lowest (*ranking = 6*). Open questions regarding feedback and improvement proposals were also asked. Participants rated their immersion using the *Immersion* subscale of the Technology Usage Inventory (TUI) [45].

3.5 Participants

We recruited 20 participants (14 male, 6 female) aged 18-57 (*M*=24.00, *SD*=7.90) via notice boards and email lists at Ulm university. All participants owned a driver's license. On 5-point Likert scales (*1=strongly disagree*, *5=strongly agree*), participants reported high interest in AVs (*M*=4.05; *SD*=.94), believed that such a system will ease their lives (*M*=3.95; *SD*=.94) but were unsure about whether such a system would become reality by 2030 (*M*=3.45; *SD*=1.19). Participants' experience with VR varied strongly from no experience at all (=1) to a lot of experience (=7; *M*=3.25, *SD*=1.68, *Mdn*=3.0, $IQR = 2.0 - 4.25$). After the study, participants were asked whether they noticed the described "gain" factor and what their estimate for this factor is. While responses varied from 0.5 to 4.0, most participants were able to rate this correctly (*Mdn*=2.0, $IQR = 2.0 - 2.0$).

4 RESULTS

We report descriptive and inferential statistics. While participants encountered **12** conditions, we report the combined values for *with* and *without* (averaged with their mean value) traffic unless otherwise stated as values between the conditions *with* and *without* traffic were not significantly different (see Section With vs. Without Traffic). For parametric data, pairwise t-tests were used as post-hoc test. Post-hoc tests were carried out with Bonferroni correction.

4.1 With vs. Without Traffic

We compared all concepts for the effects of traffic on cognitive load, affective state, and trust between their ratings *with* and *without* traffic. Interestingly, cognitive load was reported to be lower in almost all ***with*** *traffic* conditions (see Figure 4). We used t-tests for parametric and Wilcoxon signed-rank tests for non-parametric data. We found no significant differences in any of the observed dependent variables.

4.2 Affective State

Participants' affective state in terms of dominance was overall relatively high. The dominance score was statistically significantly different for concepts, $F(3, 63) = 6.35$, $p<.001$, η_p^2=.13. Post-hoc analyses revealed that the *Baseline* (*M*=5.63, *SD*=.93) received, compared to the *Arrows* (*M*=4.25, *SD*=1.40; *t*(19)=4.19, *adj. p*=.007) and the *Zebra* (*M*=4.45, *SD*=1.53; *t*(19)=3.43, *adj. p*=.04), statistically significantly higher dominance values. Participants seemed to have felt influenced in their decision-making.

4.3 Cognitive Load

The raw NASA-TLX was used to assess cognitive load. Overall, cognitive load was low for all concepts (range: *M*=3.68, *SD*=1.94 *Zebra* to *M*=5.24, *SD*=3.02 *no visualization*). The overall score was significantly different for the concepts $F(3, 66) = 6.44$, $p<.001$, η_p^2=.06. Post-hoc tests revealed that the *Baseline* (*M*=5.24, *SD*=3.02) received significantly higher ratings compared to *Text* (*M*=3.68, *SD*=1.94; *t*(19)=4.02, *adj. p*=.01) and *Arrows* (*M*=3.78, *SD*=2.02; *t*(19)=3.60, *adj. p*=.03). The *Auditory* concept received significantly higher ratings (*M*=4.91,*SD*=2.60) than the *Text* concept (*M*=3.68, *SD*=1.94; *t*(19)=4.11, *adj. p*=.009). The *Text* also received significantly lower ratings compared to the *Recognition* concept (*M*=5.19, *SD*=2.73; *t*(19)=-3.44, *adj. p*=.04).

A significant effect was also shown for the subcale mental effort $F(3, 61) = 6.58$, $p<.001$, η_p^2=.10. Post-hoc tests showed that the *Baseline* received significantly worse (higher) ratings compared to the *Arrows* (*t*(19)=3.99, *adj. p*=.01). The *Text* (*t*(19)=-3.41, *adj. p*=.045) and the *Arrows* (*t*(19)=-4.01, *adj. p*=.01) received significantly better (lower) ratings compared to the *Recognition*. The *Arrows* were also rated significantly better than the *Zebra* (*t*(19)=-3.44, *adj. p*=.04). This indicates that the arrows were the easiest to understand. The *Recognition* (*M*=7.33, *SD*=4.52) received almost the same rating as the *Baseline* (*M*=7.05, *SD*=4.32). This could indicate that for the task *getting to the other side of the vehicle*, *awareness* information does not aid mental effort.

4.4 Predictability/Understanding, Propensity to and Trust in Automation

We measured the *Propensity to Trust* subscale of the *Trust in Automation* questionnaire [44] once before and once after all conditions. A Wilcoxon signed-rank test revealed that *Propensity to Trust* was not significantly different after experiencing the study (before: *M*=2.85, *SD*=.62; after: *M*=2.98, *SD*=.50; *W*=32, *Z*=-1.21, *p*=.21, *r*=-.162). In another experiment related to external communication of AV, such an increase was shown [19].

A Friedman's ANOVA showed a significant difference in the mean ratings for the trust [44] score (χ^2 (5)=31.6, $p<.001$). Post-hoc tests showed that the *Baseline* (*M*=2.58, *SD*=.87) received significantly lower trust values compared to all other concepts except the *Recognition* concept.

The *Predictability/Understanding* subscale of the *Trust in Automation* questionnaire [44] was significantly different $F(3, 57) = 7.5$, η_p^2=.18. Post-hoc tests showed that the *Baseline* (*M*=2.43, *SD*=.75) received significantly lower values than the *Auditory* (*M*=3.13, *SD*=.52; *t*(19)=-5.98, *adj. p*<.001), the *Text* (*M*=3.32, *SD*=.70; *t*(19)=-6.66, *adj. p*<.001) and the *Arrows* concept (*M*=3.35, *SD*=.56; *t*(19)=-5.80, *adj. p*<.001). This was expected as the concepts explain the status of the traffic. The *Zebra* and the *Recognition* seem not to be intuitively understandable.

4.5 Condition Preferences

Participants ranked the **6** concepts. A lower mean corresponds to a higher preference, i.e., 1.0 equals highest preference. There was a clear rating, no communication (*Baseline*) was rated the worst (*M*=5.30, *SD*=.86) followed by the *Auditory* (*M*=4.15, *SD*=1.27) and the *Recognition* concept (*M*=3.90, *SD*=1.77). The *Zebra* received the third best ranking (*M*=3.15, *SD*=1.50), *Text* the second best (*M*=2.85, *SD*=.99) and the *Arrows* concept was clearly preferred (*M*=1.65, *SD*=1.23).

A Friedman's ANOVA showed a significant difference in the mean rankings (χ^2 (5)=44.5, $p<.001$). Post-hoc tests showed that the *Baseline* was rated significantly worse than the *Arrows*, the *Text*,

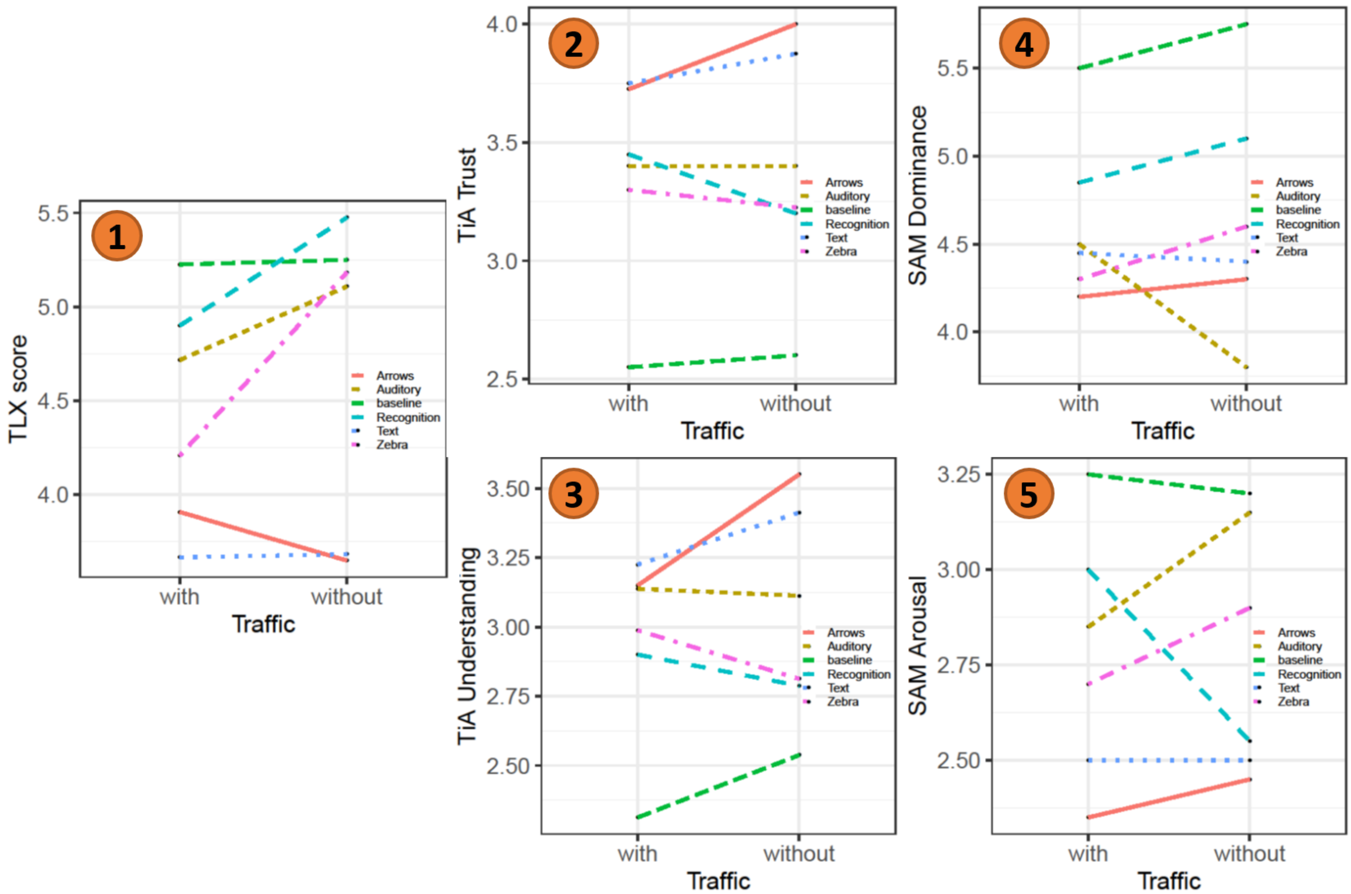

Figure 4: Effect of traffic on (1) cognitive load, (2) trust, (3) understanding, (4) dominance, and (5) arousal per concept.

and the *Zebra* concept. The *Arrows* concept was rated significantly better than the *Recognition* and the *Auditory* concept.

4.6 Safety, Trustworthiness, Comprehensibility, Unambiguousness

A Friedman's ANOVA showed a significant difference in the mean ratings for safety (χ^2 (5)=27.6, p<.001), trustworthiness (χ^2 (5)=34.3, p<.001), comprehensibility (χ^2 (5)=48.3, p<.001), and unambiguousness (χ^2 (5)=52.5, p<.001). In the following, the results of post-hoc tests are reported.

Safety: The *Baseline* (*M*=3.65, *SD*=1.57) was rated significantly worse compared to the *Text* (*M*=5.33, *SD*=1.15) and *Arrows* (*M*=5.43, *SD*=1.00) and the *Arrows* significantly higher than the *Recognition* (*M*=4.00, *SD*=1.69). Participants felt safer with explicit communication and especially with communication indicating permission to cross.

Trustworthiness: The *Baseline* (*M*=3.30, *SD*=1.41) was rated significantly worse compared to the *Auditory* (*M*=4.93, *SD*=1.29), the *Text* (*M*=5.34, *SD*=1.38), and the *Arrows* (*M*=5.30, *SD*=1.12). Explicit text-based communication (*Auditory* and *Text*) and the well-known symbol *Arrows* were trusted higher, maybe because of the familiarity.

Comprehensibility: Participants rated the *Baseline* (*M*=2.34, *SD*=1.28) significantly worse compared to the *Auditory* (*M*=5.28, *SD*=1.40), the *Text* (*M*=5.88, *SD*=1.17), the *Arrows* (*M*=6.05, *SD*=.79), and the *Zebra* (*M*=4.88, *SD*=1.70). The *Text* was rated significantly higher than the *Recognition* (*M*=4.50, *SD*=1.97). The *Baseline* and the *Recognition* concept were not easily comprehensible compared to all other concepts.

Unambiguousness: The *Baseline* (*M*=2.30, *SD*=1.31) received significantly worse ratings compared to the *Auditory* (*M*=5.35, *SD*=1.53), the *Text* (*M*=6.08, *SD*=1.00), and the *Arrows* (*M*=5.75, *SD*=1.03). The *Text* was also rated significantly higher than the *Zebra* (*M*=4.73, *SD*=1.53) and the *Recognition* (*M*=4.23, *SD*=1.99).

4.7 Reasonable, Necessary, Appropriate

The mean value for the item rating the explicit communication as reasonable was very high (*M*=6.20, *SD*=.95). The item rating the necessity of such communication also received a high value (*M*=5.35, *SD*=1.76). Comparing the ratings for appropriateness of auditory (*M*=3.80, *SD*=2.02) and visual (*M*=6.15, *SD*=.67) communication, a Wilcoxon signed-rank test revealed that visual communication was rated significantly more appropriate (*W*=130, *Z*=-3.20, *p*=.001, *r*=-.427).

4.8 Walk Path and Duration

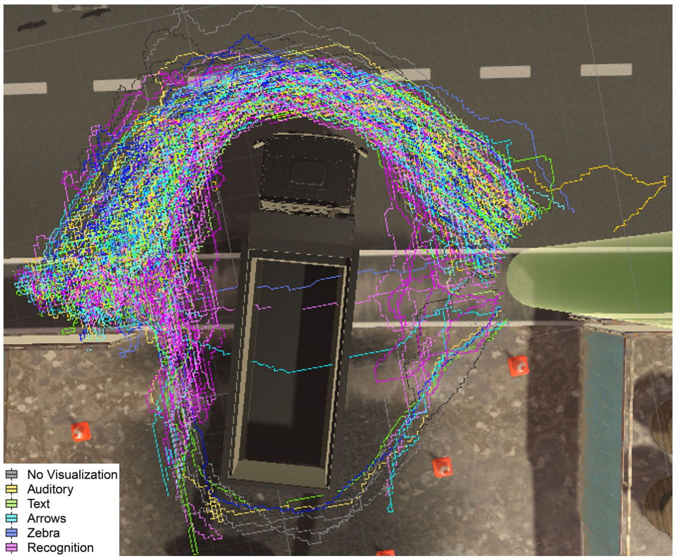

Figure 5: Walk paths of all participants per condition.

As depicted in Figure 5, most participants walked in front of the vehicle. The three lines crossing through the vehicle were caused by participants walking prior to the vehicle's arrival. In 9/240 (3.75%) of trials, participants walked **behind** the vehicle, 6 of which occurred in the *Baseline*. One walk behind the vehicle each occurred for the *Text* (green), *Zebra* (blue), and the *Auditory* (yellow) concept. Interestingly, for the *Recognition* concept, many participants tried out the visualization and then decided to cross **in front of** the vehicle. No direction was instructed by the experimenter.

Regarding the duration needed for reaching the goal, only the values for *no traffic* were evaluated. For all conditions *with traffic*, traffic slightly differed in the arrival time of vehicles to prevent participants from knowing the exact timings. Therefore, the duration values of the *with traffic* conditions were not evaluated. A Friedman's ANOVA showed a significant difference in the mean ratings for the trust [44] score (χ^2 (5)=40.86, p<.001). Post-hoc tests showed that participants needed significant more time in the *Baseline* (M=22.94 s, SD=18.43) compared to all other systems other than *Recognition* (M=19.00 s, SD=12.17). Participants were significantly faster in for all concepts other than the *Baseline* compared to the *Recognition* system (*Auditory*: M=11.50 s, SD=5.27; *Text*: M=11.90 s, SD=7.81; *Arrows*: M=11.52 s, SD=4.91; *Zebra*: M=12.21 s, SD=9.83).

4.9 Open Feedback

In the open feedback, six participants stated that multimodal feedback would "not be bad, for example, for people with vision impairments" [P20]. The distinction between explicit communication for the conditions *with* and *without* traffic was liked and was also requested for the *Zebra* ("Projection on the ground: communicate even when the road is not clear" [P7]). However, the projection was also rated as "almost counterproductive, as I looked at the ground and was tempted to look only at the projection and not at the traffic itself" [P2]. The auditory feedback gave seven participants the feeling of being "pressured" [P10]. [P15] also stated that "The auditory signals were rather irritating. They distracted from the sounds of traffic." [P10] stated that the additional communication of the vehicle's intention would have been beneficial. [P9] discussed whether directing people towards the back of the vehicle would be more appropriate to avoid having to walk on the street. As we did not prohibit the participants to walk past the back, it is interesting to see that [P9] still crossed in front.

5 DISCUSSION

In the following, we discuss the findings in the light of legal and ethical concerns, how such vehicles fit into the work on public displays, and address practical implications.

5.1 Only Display Warnings or Make Truck Transparent

In the light of regulatory and legal questions [28], the ISO technical report 23049:2018 [1] advises using external communication only to convey the own intention of an AV. This was evaluated in this work's study with the concept *visual Recognition*. However, other concepts were clearly favored (see Section Condition Preferences). That's why another form of communication seems advantageous: displaying a warning not to walk when other vehicles are approaching but not to display explicit "Go" messages. Not displaying any message, however, seems unfeasible as this will most likely be interpreted as an implicit "Go". Therefore, we propose to display, even when no other vehicles are detected, a message or sign that might resemble "Be cautious" (see Figure 6; not part of the study). Another possibility would be to avoid interpreting the situation but to make the vehicle transparent trough video streaming (see Figure 6 (3)). Such technology could be applied via AR or an attached display. Gomes et al. [32] used AR to display the street in front of a truck to improve take overs. Van Amersfoorth et al. [69] propose to use AR-enabled windshields to make objects in front translucent. Samsung showed such an application with attached displays at the rear of a truck [63].

5.2 Autonomous Vehicles as Public Displays

With the advance of AVs and their technology, numerous novel use cases can be imagined. In the reported study, a highly automated truck aids pedestrians in crossing a street safely. Other researchers have shown the use of external displays for advertisement or personalization [16]. Such displays essentially become *Public Displays*, a well-researched area. Public displays were, for example, concerned with *how to engage* bystanders [8, 68] and when such displays are actually looked at [38]. Further work proposed interaction phases [70] or a user interaction framework [29]. Public displays were already used for presenting navigation cues [46]. AVs acting as Public Displays as envisioned in this work, however, pose novel challenges. While gaining the attention of the person, for example, is no problem the possibilities of *moving Public Displays* seem unexplored.

Figure 6: Concept displaying (1) "blocked" with and (2) "Caution" without traffic, hence, not explicitly stating that it is safe to cross. (3) showcases a display showing the other side of the vehicle, therefore, adding some "transparency".

5.3 Autonomous Vehicles as Monitoring Devices

In this work, a highly automated truck surveys the environment for oncoming traffic. Various other use cases could be envisioned for such a monitoring service. However, data privacy issues could emerge. Who will be in charge of the data? Private companies or governments? Such technology could also be easily abused. China, for example, already uses cameras to track whether pedestrians cross red lights [21]. With additional access to millions or even billions of vehicles equipped with three [75] or even more cameras and latest face recognition methods [47], people could be continuously surveyed. The benefits and drawbacks of such approaches must be researched and discussed.

5.4 People's "Obedience" of or "Overtrust" in eHMIs

While [P9] stated that it would maybe be beneficial to cross in the back of the truck, [P9] still walked in front of the truck. Only in 3/240 (1.25%) of the trials, participants walked behind the vehicle with external communication present. Humans tend to rely on technical devices without actually understanding the technology and its limitations [34]. However, technology can and often does fail. Calibrated trust [59] is, therefore, already the aim for the operation of AVs. This should also be the goal for external communication of AVs [36]. Hou et al. [37] already showed that cyclists tend to rely on eHMIs and, therefore, stop applying necessary safety procedures. Our findings point towards the same direction. We do not claim that it is always safer to cross in front of the vehicle, i.e., on the street, however, we believe that traffic is more predictable compared to construction site traffic, therefore, allowing easier communication of the state of traffic. The aforementioned possibility of displaying the street via a display connected to a camera [32, 63] is a neutral, non-interpreting alternative. Our concept did not include traffic on the side of the pedestrian. Drivers could use the information presented on the highly automated truck to drive past it, creating possibly dangerous situations as pedestrians could stop looking at the other lanes as well. Not explicitly stating that the street is free (i.e., by only displaying warnings) or only displaying it when all lanes are free seems favorable.

5.5 Practical Implications

Sensors are constantly exposed to environmental influences. The same holds for external communication technologies. This is especially important in areas with increased exposure to potentially damaging conditions, e.g., construction sites. Therefore, if such concepts were to be included in autonomous trucks, special care has to be considered for securing these implementations as part of general maintenance. No significant differences were found for the duration of the crossing time for all concepts excluding *Recognition*. It seems that *how* the information *the street is free* was conveyed only played a minor part. It was, however, preferred to have a clear indication of whether the street is blocked or free compared to the *Recognition* concept showing one's own perceived position. The *Arrows* concept was clearly preferred. However, as this could also display the *intention* of the vehicle to start, the explanation was necessary. Unambiguousness of concepts should, therefore, has to be targeted, for example via education of pedestrians as suggested by Faas et al. [27].

6 LIMITATIONS

Transferability to real-world scenarios is, as a VR setup was used, limited. We focus mostly on visual concepts, therefore, auditory or tactile concepts may be underevaluated. Group size as an important factor for crossing decisions [61] was set to 1. While this is common in the methodology on evaluating eHMIs, future work should study its influence. The studied concepts do not include a temporal component, i.e., "free/busy for X seconds". This could further improve safety in that pedestrians are more willing to wait or are aware of temporal limitations. However, problems were reported in using countdown timers at intersections [3]. Therefore, this should be studied in future work.

7 CONCLUSION & FUTURE WORK

External communication of AVs is mostly researched in the scenario *pedestrian crosses in front of an AV*. However, with highly automated trucks on the horizon, communication of these vehicles with people has to be explored. Having to sometimes remain partially on the street infuriates drivers and pedestrians are, due to impatience, tempted to walk past. We present concepts for a highly automated truck to act as a "moving signaling" to show whether it is safe to walk past the vehicle. A clear indication of the street was favored by the VR study participants (*N*=20). Only presenting the awareness of the surrounding people combined with a color-coded rating of the movement was not intuitively grasped and disliked. In the next step, we intend to test such a system with a special focus on car drivers.

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REFERENCES

[1] ISO/TR 23049:2018. 2018. *Road Vehicles: Ergonomic Aspects of External Visual Communication from Automated Vehicles to Other Road Users.* Standard. International Organization for Standardization.
[2] Claudia Ackermann, Matthias Beggiato, Sarah Schubert, and Josef F Krems. 2019. An experimental study to investigate design and assessment criteria: what is important for communication between pedestrians and automated vehicles? *Applied ergonomics* 75 (2019), 272–282.
[3] Milaszewicz Barbara. 2018. The issue of using countdown timers at intersections with traffic lights: A literature review. In *2018 XI International Science-Technical Conference Automotive Safety*. IEEE, IEEE, New York, NY, USA, 1–7.
[4] Mercedes Benz. 2015. Der Mercedes-Benz F 015 Luxury in Motion. **https://www.mercedes-benz.com/de/innovation/forschungsfahrzeug-f-015-luxury-in-motion/**. [Online; accessed: 07-DECEMBER-2019].
[5] Marc-Philipp Böckle, Anna Pernestål Brenden, Maria Klingegård, Azra Habibovic, and Martijn Bout. 2017. SAV2P: Exploring the Impact of an Interface for Shared Automated Vehicles on Pedestrians' Experience. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications Adjunct* (Oldenburg, Germany) *(AutomotiveUI '17)*. Association for Computing Machinery, New York, NY, USA, 136–140. **https://doi.org/10.1145/3131726.3131765**
[6] Margaret M Bradley and Peter J Lang. 1994. Measuring emotion: the self-assessment manikin and the semantic differential. *Journal of behavior therapy and experimental psychiatry* 25, 1 (1994), 49–59.
[7] Robin N. Brewer and Vaishnav Kameswaran. 2018. Understanding the Power of Control in Autonomous Vehicles for People with Vision Impairment. In *Proceedings of the 20th International ACM SIGACCESS Conference on Computers and Accessibility* (Galway, Ireland) *(ASSETS '18)*. Association for Computing Machinery, New York, NY, USA, 185–197. **https://doi.org/10.1145/3234695.3236347**
[8] Harry Brignull and Yvonne Rogers. 2003. Enticing people to interact with large public displays in public spaces. In *Proceedings of INTERACT*, Vol. 3. Brighton, UK, IOS Press, Amsterdam, The Netherlands, 17–24.
[9] Christopher G Burns, Luis Oliveira, Peter Thomas, Sumeet Iyer, and Stewart Birrell. 2019. Pedestrian decision-making responses to external human-machine interface designs for autonomous vehicles. In *2019 IEEE Intelligent Vehicles Symposium (IV)*. IEEE, IEEE, New York, NY, USA, 70–75.
[10] Chia-Ming Chang, Koki Toda, Takeo Igarashi, Masahiro Miyata, and Yasuhiro Kobayashi. 2018. A Video-Based Study Comparing Communication Modalities between an Autonomous Car and a Pedestrian. In *Adjunct Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Toronto, ON, Canada) *(AutomotiveUI '18)*. Association for Computing Machinery, New York, NY, USA, 104–109. **https://doi.org/10.1145/3239092.3265950**
[11] Chia-Ming Chang, Koki Toda, Takeo Igarashi, Masahiro Miyata, and Yasuhiro Kobayashi. 2018. A Video-Based Study Comparing Communication Modalities between an Autonomous Car and a Pedestrian. In *Adjunct Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Toronto, ON, Canada) *(AutomotiveUI '18)*. Association for Computing Machinery, New York, NY, USA, 104–109. **https://doi.org/10.1145/3239092.3265950**
[12] Chia-Ming Chang, Koki Toda, Daisuke Sakamoto, and Takeo Igarashi. 2017. Eyes on a Car: An Interface Design for Communication between an Autonomous Car and a Pedestrian. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Oldenburg, Germany) *(AutomotiveUI '17)*. Association for Computing Machinery, New York, NY, USA, 65–73. **https://doi.org/10.1145/3122986.3122989**
[13] Vicky Charisi, Azra Habibovic, Jonas Andersson, Jamy Li, and Vanessa Evers. 2017. Children's Views on Identification and Intention Communication of Self-Driving Vehicles. In *Proceedings of the 2017 Conference on Interaction Design and Children* (Stanford, California, USA) *(IDC '17)*. Association for Computing Machinery, New York, NY, USA, 399–404. **https://doi.org/10.1145/3078072.3084300**
[14] Arun Chatterjee, Richard A Staley, Robert Stammer, et al. 1986. *Curb space management strategies for Nashville.* Technical Report. United States. Dept. of Transportation. Office of the Secretary of Transportation.
[15] Michael Clamann, Miles Aubert, and Mary L Cummings. 2017. *Evaluation of vehicle-to-pedestrian communication displays for autonomous vehicles.* Technical Report. The National Academies of Sciences, Engineering, and Medicine.
[16] Ashley Colley, Jonna Häkkilä, Meri-Tuulia Forsman, Bastian Pfleging, and Florian Alt. 2018. Car Exterior Surface Displays: Exploration in a Real-World Context. In *Proceedings of the 7th ACM International Symposium on Pervasive Displays* (Munich, Germany) *(PerDis '18)*. Association for Computing Machinery, New York, NY, USA, Article 7, 8 pages. **https://doi.org/10.1145/3205873.3205880**
[17] Mark Colley and Rukzio Rukzio. 2020. A Design Space for External Communication of Autonomous Vehicles. In *Proceedings of the 12th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '20)*. ACM, Association for Computing Machinery, New York, NY, USA. **https://doi.org/10.1145/3409120.3410646** accepted.
[18] Mark Colley and Rukzio Rukzio. 2020. Towards a Design Space for External Communication of Autonomous Vehicles. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, Hawaii USA) *(CHI '20)*. ACM, Association for Computing Machinery, New York, NY, USA. **https://doi.org/10.1145/3334480.3382844**
[19] Mark Colley, Marcel Walch, Jan Gugenheimer, Ali Askari, and Rukzio Rukzio. 2020. Towards Inclusive External Communication of Autonomous Vehicles for Pedestrians with Vision Impairments. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, Hawaii USA) *(CHI '20)*. ACM, Association for Computing Machinery, New York, NY, USA, 1–14. **https://doi.org/10.1145/3313831.3376472**
[20] Mark Colley, Marcel Walch, Jan Gugenheimer, and Enrico Rukzio. 2019. Including People with Impairments from the Start: External Communication of Autonomous Vehicles. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings* (Utrecht, Netherlands) *(AutomotiveUI '19)*. Association for Computing Machinery, New York, NY, USA, 307–314. **https://doi.org/10.1145/3349263.3351521**
[21] Rogier Creemers. 2018. China's social credit system: an evolving practice of control.
[22] Koen De Clercq, Andre Dietrich, Juan Pablo Núñez Velasco, Joost De Winter, and Riender Happee. 2019. External human-machine interfaces on automated vehicles: effects on pedestrian crossing decisions. *Human factors* 61, 8 (2019), 1353–1370.
[23] Shuchisnigdha Deb, Daniel W. Carruth, Muztaba Fuad, Laura M. Stanley, and Darren Frey. 2020. Comparison of Child and Adult Pedestrian Perspectives of External Features on Autonomous Vehicles Using Virtual Reality Experiment. In *Advances in Human Factors of Transportation*, Neville Stanton (Ed.). Springer International Publishing, Cham, 145–156.
[24] Shuchisnigdha Deb, Lesley J Strawderman, and Daniel W Carruth. 2018. Investigating pedestrian suggestions for external features on fully autonomous vehicles: A virtual reality experiment. *Transportation research part F: traffic psychology and behaviour* 59 (2018), 135–149.
[25] Shuchisnigdha Deb, B. Warner, S. Poudel, and S. Bhandari. 2016. Identification of external design preferences in autonomous vehicles. In *Proc. IIE Res. Conf.* Institute of Industrial Engineers, Peachtree Corners, GA, USA, 69–44.
[26] Debargha Dey, Francesco Walker, Marieke Martens, and Jacques Terken. 2019. Gaze Patterns in Pedestrian Interaction with Vehicles: Towards Effective Design of External Human-Machine Interfaces for Automated Vehicles. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Utrecht, Netherlands) *(AutomotiveUI '19)*. Association for Computing Machinery, New York, NY, USA, 369–378. **https://doi.org/10.1145/3342197.3344523**
[27] Stefanie M. Faas, Andrea C. Kao, and Martin Baumann. 2020. A Longitudinal Video Study on Communicating Status and Intent for Self-Driving Vehicle – Pedestrian Interaction. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–14. **https://doi.org/10.1145/3313831.3376484**
[28] Daniel J Fagnant and Kara Kockelman. 2015. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice* 77 (2015), 167–181.
[29] Matthias Finke, Anthony Tang, Rock Leung, and Michael Blackstock. 2008. Lessons Learned: Game Design for Large Public Displays. In *Proceedings of the 3rd International Conference on Digital Interactive Media in Entertainment and Arts* (Athens, Greece) *(DIMEA '08)*. Association for Computing Machinery, New

York, NY, USA, 26–33. https://doi.org/10.1145/1413634.1413644

[30] Evelyn Florentine, Mark Adam Ang, Scott Drew Pendleton, Hans Andersen, and Marcelo H. Ang. 2016. Pedestrian Notification Methods in Autonomous Vehicles for Multi-Class Mobility-on-Demand Service. In *Proceedings of the Fourth International Conference on Human Agent Interaction* (Biopolis, Singapore) *(HAI '16)*. Association for Computing Machinery, New York, NY, USA, 387–392. https://doi.org/10.1145/2974804.2974833

[31] Lex Fridman, Bruce Mehler, Lei Xia, Yangyang Yang, Laura Yvonne Facusse, and Bryan Reimer. 2017. To walk or not to walk: Crowdsourced assessment of external vehicle-to-pedestrian displays.

[32] Pedro Gomes, Cristina Olaverri-Monreal, and Michel Ferreira. 2012. Making vehicles transparent through V2V video streaming. *IEEE Transactions on Intelligent Transportation Systems* 13, 2 (2012), 930–938.

[33] Uwe Gruenefeld, Sebastian Weiß, Andreas Löcken, Isabella Virgilio, Andrew L. Kun, and Susanne Boll. 2019. VRoad: Gesture-Based Interaction between Pedestrians and Automated Vehicles in Virtual Reality. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings* (Utrecht, Netherlands) *(AutomotiveUI '19)*. Association for Computing Machinery, New York, NY, USA, 399–404. https://doi.org/10.1145/3349263.3351511

[34] Patricia L Hardré. 2016. When, how, and why do we trust technology too much? In *Emotions, Technology, and Behaviors*. Elsevier, Amsterdam, The Netherlands, 85–106.

[35] Sandra G Hart and Lowell E Staveland. 1988. Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In *Advances in psychology*. Vol. 52. Elsevier, Amsterdam, The Netherlands, 139–183.

[36] Kai Holländer, Philipp Wintersberger, and Andreas Butz. 2019. Overtrust in External Cues of Automated Vehicles: An Experimental Investigation. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Utrecht, Netherlands) *(AutomotiveUI '19)*. Association for Computing Machinery, New York, NY, USA, 211–221. https://doi.org/10.1145/3342197.3344528

[37] Ming Hou, Karthik Mahadevan, Sowmya Somanath, Ehud Sharlin, and Lora Oehlberg. 2020. Autonomous Vehicle-Cyclist Interaction: Peril and Promise. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3313831.3376884

[38] Elaine M. Huang, Anna Koster, and Jan Borchers. 2008. Overcoming Assumptions and Uncovering Practices: When Does the Public Really Look at Public Displays?. In *Pervasive Computing*, Jadwiga Indulska, Donald J. Patterson, Tom Rodden, and Max Ott (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 228–243.

[39] Christopher R. Hudson, Shuchisnigdha Deb, Daniel W. Carruth, John McGinley, and Darren Frey. 2019. Pedestrian Perception of Autonomous Vehicles with External Interacting Features. In *Advances in Human Factors and Systems Interaction*, Isabel L. Nunes (Ed.). Springer International Publishing, Cham, 33–39.

[40] Satish Jeyachandran. 2020. Introducing the 5th-generation Waymo Driver: Informed by experience, designed for scale, engineered to tackle more environments. https://blog.waymo.com/2020/03/introducing-5th-generation-waymo-driver.html [Online; accessed 24-MARCH-2020].

[41] Radka Kantová. 2017. Construction Machines as a Source of Construction noise. *Procedia engineering* 190 (2017), 92–99.

[42] Christina Kaß, Stefanie Schoch, Frederik Naujoks, Sebastian Hergeth, Andreas Keinath, and Alexandra Neukum. 2020. Standardized Test Procedure for External Human–Machine Interfaces of Automated Vehicles. *Information* 11, 3 (2020), 173.

[43] Shinya Kitayama, Toshiyuki Kondou, Hirokazu Ohyabu, Masaaki Hirose, Haneda Narihiro, and Ryuta Maeda. 2017. *Display System for Vehicle to Pedestrian Communication.* Technical Report. SAE Technical Paper.

[44] Moritz Körber. 2019. Theoretical Considerations and Development of a Questionnaire to Measure Trust in Automation. In *Proceedings of the 20th Congress of the International Ergonomics Association (IEA 2018)*, Sebastiano Bagnara, Riccardo Tartaglia, Sara Albolino, Thomas Alexander, and Yushi Fujita (Eds.). Springer International Publishing, Cham, 13–30.

[45] Oswald D Kothgassner, Anna Felnhofer, Nathalie Hauk, Elisabeth Kastenhofer, Jasmine Gomm, and Ilse Kryspin-Exner. 2013. Technology Usage Inventory (TUI).

[46] Christian Kray, Gerd Kortuem, and Antonio Krüger. 2005. Adaptive Navigation Support with Public Displays. In *Proceedings of the 10th International Conference on Intelligent User Interfaces* (San Diego, California, USA) *(IUI '05)*. Association for Computing Machinery, New York, NY, USA, 326–328. https://doi.org/10.1145/1040830.1040916

[47] Mate Krišto and Marina Ivasic-Kos. 2018. An overview of thermal face recognition methods. In *2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO)*. IEEE, IEEE, New York, NY, USA, 1098–1103.

[48] Yee Mun Lee, Ruth Madigan, Jorge Garcia, Andrew Tomlinson, Albert Solernou, Richard Romano, Gustav Markkula, Natasha Merat, and Jim Uttley. 2019. Understanding the Messages Conveyed by Automated Vehicles. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Utrecht, Netherlands) *(AutomotiveUI '19)*. Association for Computing Machinery, New York, NY, USA, 134–143. https://doi.org/10.1145/3342197.3344546

[49] Yeti Li, Murat Dikmen, Thana G. Hussein, Yahui Wang, and Catherine Burns. 2018. To Cross or Not to Cross: Urgency-Based External Warning Displays on Autonomous Vehicles to Improve Pedestrian Crossing Safety. In *Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Toronto, ON, Canada) *(AutomotiveUI '18)*. Association for Computing Machinery, New York, NY, USA, 188–197. https://doi.org/10.1145/3239060.3239082

[50] Andreas Löcken, Carmen Golling, and Andreas Riener. 2019. How Should Automated Vehicles Interact with Pedestrians? A Comparative Analysis of Interaction Concepts in Virtual Reality. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Utrecht, Netherlands) *(AutomotiveUI '19)*. Association for Computing Machinery, New York, NY, USA, 262–274. https://doi.org/10.1145/3342197.3344544

[51] Victor Malmsten Lundgren, Azra Habibovic, Jonas Andersson, Tobias Lagström, Maria Nilsson, Anna Sirkka, Johan Fagerlönn, Rikard Fredriksson, Claes Edgren, Stas Krupenia, and Dennis Saluäär. 2017. Will There Be New Communication Needs When Introducing Automated Vehicles to the Urban Context?. In *Advances in Human Aspects of Transportation*, Neville A. Stanton, Steven Landry, Giuseppe Di Bucchianico, and Andrea Vallicelli (Eds.). Springer International Publishing, Cham, 485–497.

[52] Karthik Mahadevan, Elaheh Sanoubari, Sowmya Somanath, James E. Young, and Ehud Sharlin. 2019. AV-Pedestrian Interaction Design Using a Pedestrian Mixed Traffic Simulator. In *Proceedings of the 2019 on Designing Interactive Systems Conference* (San Diego, CA, USA) *(DIS '19)*. Association for Computing Machinery, New York, NY, USA, 475–486. https://doi.org/10.1145/3322276.3322328

[53] Karthik Mahadevan, Sowmya Somanath, and Ehud Sharlin. 2018. Communicating Awareness and Intent in Autonomous Vehicle-Pedestrian Interaction. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3173574.3174003

[54] Jessica Mairs. 2017. Umbrellium develops interactive road crossing that only appears when needed. https://www.dezeen.com/2017/10/12/umbrellium-develops-interactive-road-crossing-that-only-appears-when-needed-technology/. [Online; accessed 12-DECEMBER-2019].

[55] Milecia Matthews, Girish Chowdhary, and Emily Kieson. 2017. Intent communication between autonomous vehicles and pedestrians.

[56] Natasha Merat, Tyron Louw, Ruth Madigan, Marc Wilbrink, and Anna Schieben. 2018. What externally presented information do VRUs require when interacting with fully Automated Road Transport Systems in shared space? *Accident Analysis & Prevention* 118 (2018), 244–252.

[57] Avi Chaim Mersky and Constantine Samaras. 2016. Fuel economy testing of autonomous vehicles. *Transportation Research Part C: Emerging Technologies* 65 (2016), 31–48.

[58] Dylan Moore, Rebecca Currano, G. Ella Strack, and David Sirkin. 2019. The Case for Implicit External Human-Machine Interfaces for Autonomous Vehicles. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Utrecht, Netherlands) *(AutomotiveUI '19)*. Association for Computing Machinery, New York, NY, USA, 295–307. https://doi.org/10.1145/3342197.3345320

[59] Bonnie M Muir and Neville Moray. 1996. Trust in automation. Part II. Experimental studies of trust and human intervention in a process control simulation. *Ergonomics* 39, 3 (1996), 429–460.

[60] Trung Thanh Nguyen, Kai Holländer, Marius Hoggenmueller, Callum Parker, and Martin Tomitsch. 2019. Designing for Projection-Based Communication between Autonomous Vehicles and Pedestrians. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Utrecht, Netherlands) *(AutomotiveUI '19)*. Association for Computing Machinery, New York, NY, USA, 284–294. https://doi.org/10.1145/3342197.3344543

[61] Amir Rasouli and John K Tsotsos. 2019. Autonomous vehicles that interact with pedestrians: A survey of theory and practice. *IEEE Transactions on Intelligent Transportation Systems* 21, 3 (2019), 900–918.

[62] Michael Rettenmaier, Moritz Pietsch, Jonas Schmidtler, and Klaus Bengler. 2019. Passing through the Bottleneck-The Potential of External Human-Machine Interfaces. In *2019 IEEE Intelligent Vehicles Symposium (IV)*. IEEE, IEEE, New York, NY, USA, 1687–1692.

[63] Samsung. 2015. The Safety Truck Could Revolutionize Road Safety. https://news.samsung.com/global/the-safety-truck-could-revolutionize-road-safety. [Online; accessed: 07-APRIL-2015].

[64] Scania. 2019. A new cabless concept – revealing Scania AXL. https://www.scania.com/group/en/home/newsroom/news/2019/a-new-cabless-concept-revealing-scania-axl.html. [Online; accessed

30-JUNE-2020].

[65] Ye Eun Song, Christian Lehsing, Tanja Fuest, and Klaus Bengler. 2018. External HMIs and Their Effect on the Interaction Between Pedestrians and Automated Vehicles. In *Intelligent Human Systems Integration*, Waldemar Karwowski and Tareq Ahram (Eds.). Springer International Publishing, Cham, 13–18.

[66] Lenja Sorokin, Ronee Chadowitz, and Nina Kauffmann. 2019. A Change of Perspective: Designing the Automated Vehicle as a New Social Actor in a Public Space. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI EA '19)*. Association for Computing Machinery, New York, NY, USA, 1–8. https://doi.org/10.1145/3290607.3299044

[67] stvo.de Das Portal zur Staßenverkehrsordnung (StVO). 2020. § 3 Geschwindigkeit. https://www.stvo.de/strassenverkehrsordnung/91-3-geschwindigkeit. [Online; accessed 30-JUNE-2020].

[68] Anthony Tang, Mattias Finke, Michael Blackstock, Rock Leung, Meghan Deutscher, and Rodger Lea. 2008. Designing for Bystanders: Reflections on Building a Public Digital Forum. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Florence, Italy) *(CHI '08)*. Association for Computing Machinery, New York, NY, USA, 879–882. https://doi.org/10.1145/1357054.1357193

[69] Emma van Amersfoorth, Lotte Roefs, Quinta Bonekamp, Laurent Schuermans, and Bastian Pfleging. 2019. Increasing Driver Awareness through Translucency on Windshield Displays. In *Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications: Adjunct Proceedings* (Utrecht, Netherlands) *(AutomotiveUI '19)*. Association for Computing Machinery, New York, NY, USA, 156–160. https://doi.org/10.1145/3349263.3351911

[70] Daniel Vogel and Ravin Balakrishnan. 2004. Interactive Public Ambient Displays: Transitioning from Implicit to Explicit, Public to Personal, Interaction with Multiple Users. In *Proceedings of the 17th Annual ACM Symposium on User Interface Software and Technology* (Santa Fe, NM, USA) *(UIST '04)*. Association for Computing Machinery, New York, NY, USA, 137–146. https://doi.org/10.1145/1029632.1029656

[71] Annette Werner. 2019. New colours for autonomous driving: An evaluation of chromaticities for the external lighting equipment of autonomous vehicles.

[72] Scott R Winter, Stephen Rice, Nadine K Ragbir, Bradley S Baugh, Mattie N Milner, Bee-Ling Lim, John Capps, and Emily C Anania. 2019. *Assessing Pedestrians' Perceptions and Willingness to Interact with Autonomous Vehicles*. Technical Report. Center for Advanced Transportation Mobility, Springfield, VT, USA.

[73] Su Yang. 2017. Driver behavior impact on pedestrians' crossing experience in the conditionally autonomous driving context.

[74] Jingyi Zhang, Erik Vinkhuyzen, and Melissa Cefkin. 2018. Evaluation of an Autonomous Vehicle External Communication System Concept: A Survey Study. In *Advances in Human Aspects of Transportation*, Neville A Stanton (Ed.). Springer International Publishing, Cham, 650–661.

[75] Julius Ziegler, Philipp Bender, Markus Schreiber, Henning Lategahn, Tobias Strauss, Christoph Stiller, Thao Dang, Uwe Franke, Nils Appenrodt, Christoph G Keller, et al. 2014. Making bertha drive—an autonomous journey on a historic route. *IEEE Intelligent transportation systems magazine* 6, 2 (2014), 8–20.

[76] Raphael Zimmermann and Reto Wettach. 2017. First Step into Visceral Interaction with Autonomous Vehicles. In *Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Oldenburg, Germany) *(AutomotiveUI '17)*. Association for Computing Machinery, New York, NY, USA, 58–64. https://doi.org/10.1145/3122986.3122988