Research Article

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"What's the Robo-Driver up to?" Requirements for Screen-based Awareness and Intent Communication in Autonomous Buses

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Abstract: Autonomous buses are expected to become a cornerstone of future mobility systems. Especially during their introduction, passengers may require reassurance about the vehicle's awareness of the situation on the road and of its intended next actions to further acceptance. In order to investigate the need and requirements for information about the vehicle's awareness and intent from the perspective of first-time users, we conducted two user studies in a state-of-the-art autonomous bus at public demonstration spaces. In the first study, participants underwent a demonstration ride with the bus and were then asked about their needs for awareness and intent communication. The second study took participants on a 'simulated ride' within a stationary bus, in which typical scenarios of the road ahead were presented, together with different awareness and intent cues. Our results suggest that, first, future autonomous bus passengers may be in need of such awareness and intent communication screens. Second, we found that awareness and intent communication may be of greater importance for the indication of potential hazard recognition than for indicating route directions. Third, due to their complementary strengths, none of the three compared types of visual communication (text, icon and augmented reality) should be used in isolation.

Keywords: Automotive User Interfaces, Human-Computer Interaction, Autonomous Driving, Public Transportation, User Experience, Acceptance, Trust

1 Introduction

Autonomous driving technology is expected to have significant impact on the mobility ecosystem. Especially for public transportation both in urban and rural regions, capacity and flexibility could be greatly increased with driverless buses operating at the "last mile" with ondemand routing capabilities [24, 26, 29, 21]. Such vehicles are currently mostly conceived as so-called "peoplemovers". They have a smaller size than conventional buses with a typical capacity of 8-16 persons. Thus, they can achieve faster entry and exit times (than conventional buses) and support short rides and on-demand flexibility. Such vehicles do not feature a driver seat and no traditional control mechanisms such as the steering wheel and pedals are available. The level of autonomy of such public autonomous shuttles can best be described as conditional autonomy (SAE Level 3, International SAE, [12]): The bus can drive automatically, but the whole track is pre-programmed, with no possibility of the bus making situation-aware decisions without being controlled by a human operator. While such autonomous minibuses can eventually be a very attractive means of transport, potential initial acceptance barriers must be taken into account [7].

Until now, only few studies have been conducted that look into the future acceptance of autonomous buses [20, 6]. Recent demonstration projects of autonomous buses have shown that passengers feel rather safe in automated buses [5], but, as noted by Rehrl et al. [23] this is likely caused by the presence of a human operator, who is required by law during all drives. Rehrl et al. also assume that fully 'unaccompanied' buses with higher driving speeds and mixed traffic, as can be expected to be introduced within the next years, will lead to a decrease in the passenger's sense of safety. Several field studies report a discomfort with the level of technology and service of current autonomous buses [18, 5]. A study comparing the user experience of an automated bus ride with one of a traditional group taxi drive [28] found that current obstacles

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for full acceptance of automated bus riding are related to low speed, but the authors suggest that technological improvement and optimized user interaction technology may relieve these barriers.

Trust is a central component in the context of autonomous driving [27, 13]. Trust has been found to be an important correlate of the acceptability of automation technology [9], reliance on automated systems [2], adoption of automation [8], the intention to use autonomous vehicles [3] and the technology acceptance of autonomous shuttles [19]. In contrast to control tasks in car cockpits, one needs to take into account that autonomous buses do not foresee passengers as operators who could take over full control. However, studies hitherto published on usage aspects of autonomous shuttles have not yet investigated specific awareness and intent communication techniques towards passengers with the goal to establish trust.

In most current autonomous bus design concepts (e.g. [17]), passengers will be able to activate an emergency trigger that abruptly stops the vehicle and sets up a communication channel with a remote control center. With regard to the passengers' intervention capabilities, their experience may be similar to that of autonomous trains or underground metros, which have already been put in operation. However, one cannot assume the high trust levels achieved in autonomous railway systems will be similar with autonomous buses, as these will have to deal with a much more complex environment featuring mixed traffic and flexible routing.

This paper investigates specific human interface approaches to provide awareness and intent cues to passengers of autonomous buses. Our research is based on the assumption that in the transition phase to such vehicles people may benefit from trust cues, since passengers and other road users are not yet familiar with this form of transportation and no history of successful and safe operation is available. For example, if the car in front is braking, passengers might want to know whether the bus has recognized this event (awareness) and whether it will reduce speed (intent). On a larger scale, reassuring passengers in this way and, for instance, preventing them from unnecessary presses of the emergency button, could raise the efficiency of automated mobility to a large extent. Within the remainder of this paper, we introduce our research questions, and then describe and interpret two user studies that have been conducted to answer them.

1.1 Mediating Trust in Automated Buses

While awareness and intent communication is a growing research topic when it comes to interaction with other road

users [15, 6], there is hardly any related research on passenger information systems. Previous research has looked into providing automation transparency in the context of cockpit-based tasks of (semi-automated) driving or aircraft control [11]. One main approach in this domain is to visualize automation meta-information, such as quality indicators for the involved sensors or algorithms. While this has shown to be helpful for engineers and problem solvers, we considered another approach more worthwhile in our envisaged usage context with non-expert, often first-time passengers: the explanation of system reasoning. Seppelt & Lee [25] found that drivers of semi-autonomous vehicles feel safer when the car explicitly provides combined textual information about the car action and the reason behind this action, but they also found an increase in anxiety, which may have been due to a perceived increase in workload.

An obvious means of communicating awareness and intent to passengers is the use of information screens as they are a familiar and common way of communicating background information. Beyond current ways of displaying the upcoming bus stops, the surrounding streets or the remaining travel time, these could also indicate more dynamic information about the buses' knowledge and plans. Such means of communication could be especially suitable for first-time use, which is highly important for public transportation, where people hop on and off. For such a scenario one has to ensure that information is comprehensible without habituation time or instructions. Screens could provide status information as background information to reassure potentially uneasy passengers without distracting from other activities like reading a book or monitoring one's environment. Based on these considerations, our first research question RQ1 is as follows: What are passengers' general "awareness and intent" information requirements with regard to autonomous bus operation monitoring via mounted screens? (Table 1).

1.2 Scenarios for Awareness and Intent Communication

So far, it is unknown which continuous status information passengers would like to have be displayed in which situations. The most prevalent type of information that passengers may want to have is the vehicle's recognition and handling of critical events in front of the bus (i. e. pedestrians, cyclists or other cars). A second category of cues that may be central is the indication of imminent direction of driving and any upcoming turns. For example, passengers will have most likely feel reassured by the knowledge that

Table 1: User studies and research questions addressed in this article.

Study Study 1: Demonstration Ride (see Section 2)	Research Questions addressed		
	RQ1	What are passengers' general "continuous awareness and intent" information requirements with regards to autonomous bus operation monitoring via mounted screens?	
Study 2: Simulated Ride (see Section 3)	RQ2	To which extent can awareness and intent communication provide suitable reassurance to passengers in the typical autonomous bus riding situations "braking" and "turning"?	
	RQ3	To which extent do the design elements AR, icons and text affect comprehensibility of screen-based awareness and intent communication, as well as trust and acceptance?	

a bus will not continue driving in the direction of a wall but will turn to follow the road. Our second research question RQ2 is thus as follows: To which extent can awareness and intent communication provide sufficient reassurance to passengers in the typical autonomous bus riding situations "braking" and "turning"? (Table 1).

1.3 Design Elements

As of now, there is no clear indication which design elements should be shown on an awareness and intent communication screen and how these elements are best arranged. As automated driving technology strongly relies on the visual processing of the surrounding environment, an obvious mapping of system transparency would be to show the system's view of the world, such as colored lines and forms of the recognized objects. A more elaborate version of this would be an augmented reality view (AR) that shows critical objects, which lead to a change of driving behavior regarding direction or speed, as overlays over a front scene video.

A further design element is text which has been a frequently employed way of explaining system reasoning [11, 25]. An anticipated strength of this method is its capability of expressing complex (causal) relationships. A main weakness of text is its cultural dependability and the cognitive workload that text processing presents. Another potential way of awareness and intent communications is the presentation of icons such as generic symbols for obstacles (e.g. pedestrians or cars) and actions (e.g. an arrow for indicating the direction). All three design elements are presented in Figure 2.

We chose these three design elements because our project focuses on awareness and intent communication using passenger information screens that are common in public transport nowadays. Our aim was to combine and compare representative traditional design elements (like text and icons) with an advanced one (AR) as offered by system developed in the project. The resulting third research question RQ3 is thus as follows: To which extent do the design elements AR, icons and text affect comprehensibility of screen-based awareness and intent communication, as well as trust and acceptance? (Table 1)

1.4 Addressing the Research Questions

In order to investigate aforementioned issues and research questions related to awareness and intent information for passengers in autonomous buses we conducted two user studies (see Table 1 for an overview of the studies and the associated research questions). Both studies were situated within public demonstration spaces in order to capture snapshots of spontaneous first experiences of using an autonomous bus (Figure 1). Study 1 (presented in section 2 of this paper) looked at the general requirements for dynamic information screens, thereby answering our first research question (RQ1). The study consisted of a demonstration ride with an autonomous bus that did not have dedicated awareness and intent communication features. Study 2 (see section 3) investigated in depth the design requirements for awareness and intent communication in autonomous buses, building on the fundamental requirements that had been gathered in Study 1. Participants em-



Figure 1: Autonomous minibus, type Navya ARMA, used for the studies [1, 17].

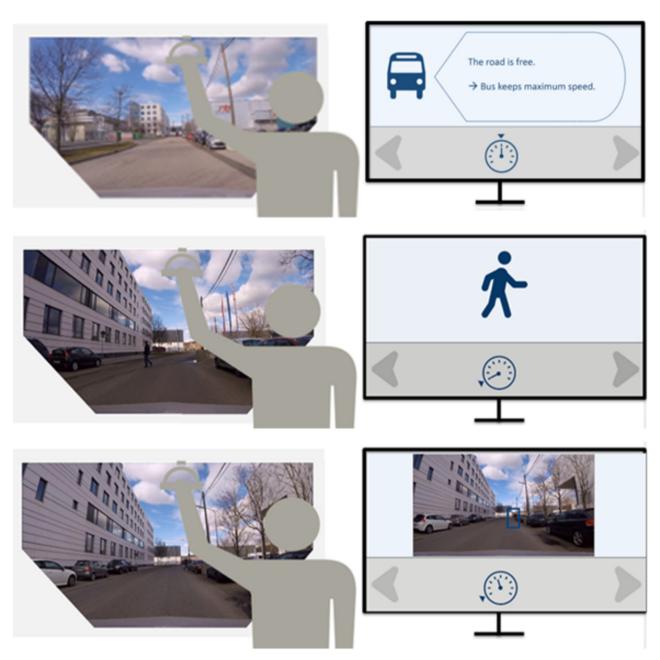


Figure 2: Exemplary illustrations of awareness and intent communication shown on the paper-based survey. Left side: the front view scenery. Right side: the three design elements that were provided as example illustrations in Study 1. On the top:: text ("the road is free -> bus keeps maximum speed"), middle: iconic (pedestrian crossing the street), bottom: AR (in both screens a pedestrian crosses the road).

barked on a 'simulated ride' during which they were seated in the same vehicle used in Study 1. In this study, the bus was stationary and the driving situations were simulated by placing a screen in the front which displayed a simulated front view of the bus ahead and additionally an awareness and intent communication display. The videos systematically differed with regard to the underlying scenario (Braking and Turning) and the type of awareness and

intent communication display (Text, Icon, AR). After their ride, passengers were asked about their needs regarding intent and awareness communication. After every presentation of a simulated scene, participants were asked about their experience and preferences with regards to the presented driving scenario (thereby addressing RQ2) and different design elements of awareness and intent communication displays (RQ3).

2 Study 1: Demonstration Ride

In order to address our first research question RQ1 on general passenger requirements for screen-based awareness and intent cues (Table 1), we conducted a user study with a state-of-the-art autonomous bus (Figure 1).

2.1 Method

Study participants joined 10-minute rides (in groups of x8) with an autonomous bus. The bus rode along a predefined route in an urban district next to the Transport Research Arena 2018 Conference and Exposition in Vienna, a major event in the international transportation community that featured several demonstrations outside the exposition center. Participation in the ride was not restricted to conference visitors, but also provided the first opportunity for the residents of the city to experience an autonomous bus. The vehicle was a Navya ARMA [17, Figure 1], which was 5 meters long, had 9 seats and drove at a speed of 10 km/h. The bus made a roundtrip between two bus stops that were about 1km apart. Each ride was made with a maximum of 8 passengers and one operator who had been trained to responsibly monitor the bus.

Before and during the ride, people did not receive any instructions other than trying out the bus. The bus interior was equipped with two outward facing screens pointing in each of the two driving directions (forward, backward). There was one indoor screen, which provided a map that showed the bus position and the surrounding area. On request the screen could further provided the operator with technical details. 32 of the participants were male and 23 female; one person did not provide demographic information. Age ranged from 15 to 55 (mean = 27.1; median = 25). Their professional and educational background ranged from pupil, student, employed and self-employed to retired. None of the participants had experienced a ride with an autonomous bus before.

After having finished the test ride, participants were asked to fill out a paper-based survey. The survey was kept fairly brief (10 minutes) in order to reduce the burden and barriers for conference visitors or passers-by to join the study. It contained a short introduction into the topic of dynamic information to passengers and also a few illustrations of potential features of such screens. These illustrations (see Figure 2) depicted an exemplary situation where a person is crossing the street in the front view (see pictures on left side), as well as respective potential realizations of an awareness and intent communication display for automated buses. Three design elements were shown

as a reference: text elements ("The road is free -> bus keeps maximum speed", see top of figure), icons (e.g. of a pedestrian crossing the street), and AR (in both screens a pedestrian crosses the road). In all three conditions, the gray lower part of the screens showed live information on bus speed (tachometer) as well as a change of direction if (the big gray arrows on the sides of the screen change blue if active).

After having seen these exemplary illustrations, participants answered two open questions related to the placement of dynamic information screens and the type of content that should be displayed on them. They then answered two further questions asked subjects to rate on a 5-point scale how helpful information screens would be and whether they would expect them to increase passenger trust. After these two questions, free text comments could be provided.

2.2 Results

In total, the data of 56 participants (32 male, 23 female) was analyzed. Age varied between 15 and 55 (mean = 27.1, median = 25). Participants reported on average to be rather open towards technology (4.3 on a scale from 1 to 5).

2.2.1 Content Type

As stated in section 2.1, participants were asked to freely state which types of content should be provided on the screen. Twenty-three participants (42%) mentioned, that standard information they were used from modern bus lines such as current speed (12/21%), the next bus stops (20/36%), the remaining travel time (16/29%), and congestions on the route (8/14%) would be important for them. Thirty-two participants (57%) explicitly listed awareness and intent aspects such as "information on the reasoning" or "basic information on the decision-making process." Related requirements that participants mentioned ranged from relatively general information ("not too much: 'everything well'; 'brake for ...') to specific recommendations, such as "information on obstacles and their distance (to assure they have been detected)".

2.2.2 Screen Placement

Table 2 provides an overview of the preferred screen positions based on the number of participants who mentioned each of the positions. Almost half of the partici-

Table 2: Overview of explicit mentions regarding the open question where the screen should be placed in the automated bus.

Positioning Aspect	Frequency/Percent of Mentions	
More than one screen	25	45%
In line of sight (front / back)	25	45%
On the side (e.g. near the door)	14	25%
At the top (i. e. not hindering sight to outside scenery)	16	28%
Available on mobile phone	4	7 %

pants (25/45%) stated that a screen should be in the line of sight. With the bidirectional seating arrangement of the tested autonomous minibus, this would require two screens in the back and the two in the front of the bus. Fourteen users (25%) said that they would prefer a positioning on the sidewall of the bus (e. g. near the door). Another preference that was listed relatively often (by 15/28%), was that a screen should be hanging from the bus ceiling to avoiding blocking sight to the outside (not only the front). Four participants (7%) mentioned the possibility of receiving information on the bus via smartphone.

2.2.3 Perceived Helpfulness and Trust

Figure 3 and Figure 4 show that most respondents generally perceived the placing of dynamic information screens in autonomous buses as positive both with regards to perceived helpfulness and trust. Comments given by participants about using the screens as awareness and intent communication were that "this could surely affect the reliability and positive attitude with regard to autonomous buses"; that "comprehensibility would be increased, less-

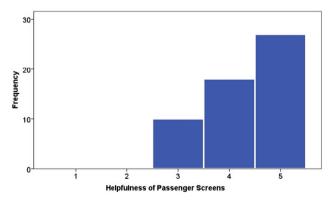


Figure 3: Helpfulness Ratings: "How helpful would passenger information screens be in automated buses?" (1: "not at all helpful", 5: "very helpful").

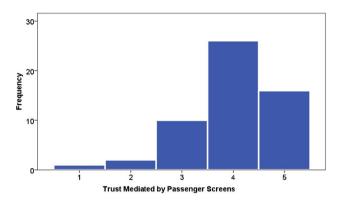


Figure 4: Trust Ratings: "Would screens with dynamic information increase passengers' trust?" (1: "not at all increased trust", 5: "strongly increased trust").

ening the feeling of a 'black box'"; and that "real time information is always helpful as the passengers can compare the displayed information and reality and when they match, the passenger trust increases". There was one person who was very skeptical about dynamic information screens, who stated: "[I don't like such screens] at all because people can't interact [with the screen] if something happens." Some mixed responses from participants who gave medium ratings were: "trust may increase for other passengers or people that are not familiar with autonomous driving", or "the other passengers will feel safer". Note that we did not find any impact of age, gender, and professional degree on perceived helpfulness or trust in such information screens in our analyses of variance.

3 Study 2: Simulated Ride

In order to build upon the general requirements for intent awareness communication services identified in Study 1, we conducted a further user study to gain more detailed guidance. To this end, this second study compared typical autonomous bus ride scenarios with regards to awareness and intent communication (research question RQ2, Table 1) and respective design elements (research question RQ3, Table 1), we conducted a second user study.

3.1 Method

At a large public research exhibition visitors were invited to inspect an autonomous bus (the same vehicle that was used in Study 1) and to participate in a research trial. As in the previous study, groups of a maximum of 8 persons could attend one session, and the duration was re-

stricted to 10-15 minutes (due to the ad-hoc character of participant recruitment at the exhibition). Participants were asked to fill out a questionnaire consisting of a number of questions on personal characteristics, demographical questions, and the subsequent test parts.

Participants first received a demonstration of the bus and some information about the related research project. They were also informed about the availability and placement of two emergency buttons. Participants were then exposed to 2 simulated bus rides with three differing types of awareness and intent communication: Text, Icon and AR. After each simulated ride they filled out the same set of questions related to comprehension, helpfulness, trust and the preparedness to press the emergency button (see Table 3). Afterwards, participants were asked to state which of the three design elements they preferred and to justify their choice in written form in a comment field.

As outlined in the introduction, the simulated bus rides were realized by showing a video on a flat screen placed on the front window, which represented the front view of a moving bus. In each video, the scene of the road ahead was displayed as if the bus driving forward, and a rectangle in the upper right part of the screen represented the dynamic information screen in the bus. The screen division was the same for all screens, with a status bar at the bottom giving rough information on the current speed of the bus and an indication in which direction the bus would turn next. The upper part of the screen was reserved for additional information given via one of the 3 investigated design elements.

Two different scenarios were investigated: The scenario "Braking" showed the front view of the street where a bus was driving with a speed of 20 km/h, until it stopped in order to let a pedestrian cross the street (Figure 5, first row). The scenario "Turning" showed the bus heading towards a sharp road curve and the dynamic screen information was designed to inform participants that the bus was indeed intending to perform a turn to stay on track (Figure 5, second row). The bus started to make the turn relatively late on purpose in order to create an ambiguous situation that might raise doubts in passengers on the situational awareness of the bus.

Study 2 was a mixed experimental design with design element (Text, Icon, AR) as within subjects factor and scenario (Braking and Turning) as between-subjects factor, and with the measures comprehension, helpfulness, trust and preparedness to press the emergency button (see Table 3 for a description of the respective rating scales). Potential effects of age group and gender were investigated as covariates. The reason for selecting this setup was mainly that it allowed relatively short sessions in the public event setting where people joined the study spontaneously. This meant that each participant watched 3 videos of about 1 minute length for one respective scenario (40 participants for Braking, and 37 for Turning), instead of all participants watching 2 scenarios x 3 videos as would have been the case with a complete repeated measures design.

Accordingly, each subject watched the same situation corresponding to the respective scenario three times, subsequently with the three design elements. In order to control for learning effects, we varied the order of design elements systematically. After each video, the following four questions were asked in form of a 5-point Likert scale and comments could be provided in text form:

At the end of each session, participants were asked to state which of the three design elements they would prefer.

Table 3: Dependent variables, related questions and answer options for Study 2.

Dependent variable	Question	Answer Options
1. Comprehension	How comprehensible was the message on the screen in this	1: Not at all comprehensible
	situation?	
		5: Very comprehensible
2. Helpfulness	To what extent did you perceive this information as helpful?	1: Not at all helpful
		•••
		5: Very helpful
3. Trust	How much trust did you have in the behavior of the automated	1: Very little trust
	bus in this situation?	_
		5: Very much trust
4. Preparedness to press	Would you have pressed the emergency button?	1: In no case
the emergency button		•••
		5: In every case



Figure 5: Snapshots of the six videos that were used in Study 2 as simulated bus rides with the three design elements Text (left), Iconic (middle) and AR (right) within the two scenarios Braking (top) and Turning (bottom). For the whole screen size, a video was shown to simulate the view out of a front window. On the upper right corner of the screen, a second video was overlaid that represented the awareness and intent display in that situation.

3.2 Results

The data of 77 participants (38 male and 39 female) was analyzed. Age varied between 17 and 90 (M = 39.3). Participants on average reported to be rather open to technology (4.13 on a scale from 1 to 5). To identify main and interaction effects and to derive pairwise differences (based on Bonferroni-adjusted p-values) we performed a generalized linear model repeated measures analysis of variance with SPSS. In case of a rejected sphericity assumption, the degrees of freedom were corrected by means of a Greenhouse & Geisser estimate. Error bars in the figures indicate 95 % confidence intervals.

3.2.1 Overall Awareness and Intent Communication

The overall reception of the dynamic information screens was positive with mean scores between 3.5 and 4.1 (with min = 1 and max = 5). Comprehensibility (see Figure 6) was the most positively rated aspect: the mean rating values were M = 4.09 (SE = .10) for both the "Breaking" and "Turning" scenario. Helpfulness and trust (Figures 7 & 8) ratings were generally lower than comprehensibility ratings (M = 3.56 and 3.63, SE = .09 and .10, respectively). Figure 9 shows that participants mostly did not feel the need to immediately stop the vehicle by pushing the emergency button (M = 1.56, SE = .74). There was no over-

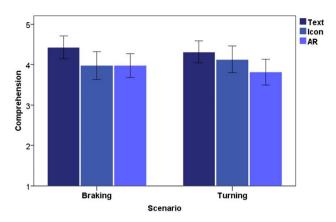


Figure 6: Mean ratings on comprehensibility, differentiated by design element (Text, Icon, and AR), with regards to the two investigated scenarios "Braking" (left) and "Turning" (right); "How comprehensible was the message on the screen in this situation?" (1: "not at all comprehensible", 5: "very comprehensible"). Error bars in the figures indicate 95 % confidence intervals.

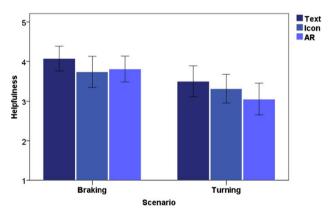


Figure 7: Mean ratings on helpfulness, differentiated by design element (Text, Icon, and AR), with regards to the two investigated scenarios "Braking" (left) and "Turning" (right); "To what extent did you perceive this information as helpful?" (1: "Not at all helpful", 5: "Very helpful"). Error bars in the figures indicate 95 % confidence intervals.

all significant impact of gender on any of the measures, but perceived helpfulness differed significantly depending on the age group, $(F(1,71)=7.34,\ p<01)$. User comments were mostly very positive, often because they felt safer with the additional information that was provided. For example, participant 71 stated that "with more information, I feel safer", and participant 64 noted that "For people like me, who are not familiar with this topic, extra information such as what will happen next and why is very comforting". The given statements confirmed that awareness about the buses' awareness and intent was important

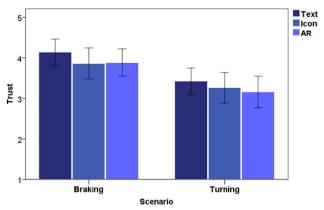


Figure 8: Mean ratings on trust, discriminated by design element (Text, Icon, and AR), with regard to the two investigated scenarios Braking (left) and Turning (right); "How much trust did you have in the behavior of the automated bus in this situation?"(1: "Very little trust", 5: "Very high trust"). Error bars in the figures indicate 95 % confidence intervals.

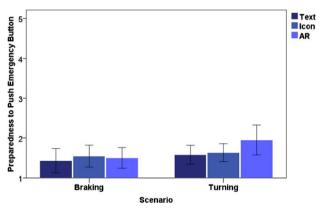


Figure 9: Mean ratings on preparedness to push emergency button, discriminated by design element (Text, Icon, and AR) and scenario (Braking and Turning); "Would you have pressed the emergency button?" (1: "Surely not", 5; "Definitely"). Error bars in the figures indicate 95 % confidence intervals.

to our test passengers. For example, participant 16 wrote "I always knew what the bus is currently 'thinking.'"

3.2.2 Influence of Design Elements

There was a significant main effect for the preparedness to press the emergency button, F(2,142) = 3.07, p = .049 (see Figure 9), and a non-significant main effect of design element on comprehensibility, F(2,142) = 2.98, p = .054 (see Figure 6). Estimated marginal means show that text-based presentations were in general rated slightly better than AR in terms of comprehensibility (difference of 0.5,

p < .01, see Figure 6), helpfulness (diff = 0.36, p = .066, see Figure 7), trust (diff = 0.28, p = .73, see Figure 8), and preparedness to press the emergency button (diff = 0.28, p < .05, Figure 9). We did not find significant differences between textual and iconic or iconic and AR presentations.

The comments provided by participants after the video viewing sessions showed that preferences were broadly spread over the three different design elements. Text was preferred by 30 % of the participants, mostly because it was seen as a means of concrete, dense and accurate information which does not leave room for interpretation.. Also, text appeared to many participants as the best way to inform about upcoming maneuvers of the bus. In this regard, participant 55 mentioned that the awareness information text "road makes a sharp turn to the right" made it unlikely that the bus would be ignoring the road curvature, even though it turned right at a late point in time.

However, some downsides of text presentation were mentioned: larger text quantities were seen as difficult to process and people without the respective language skills or visual impairments could be disadvantaged.

The iconic design element was preferred by 30 % of the participants and was seen as a good means for fast information and for preventing language barriers. Especially the "matchstick man" representing the recognized pedestrian was often mentioned as easily recognizable (participant 2). Some participants also noted the efficiency of information "without too much information, or even information overflow" (participant 45). Also, some positively contrasted it to AR: "without the film material I am not so distracted" (participant 4). However, in cases where nothing critical was being recognized, this design element tended to provide too little information resulting in uncertainty. Also, the display of an empty screen when there is no critical event, as was the case at the beginning of our study scenarios, can confuse people. Similar to AR, participants noted that to communicate the intent of an autonomous bus some additional information about the next actions of the vehicle should be provided.

AR was preferred by 40 % of participants. It received many positive comments, most prominently with regard to the marking within the dynamic live scene outside the bus "which made it clear what had actually been recognized by the system" (participant 68). For example, Participant 34 noted: "The marking of the pedestrian is useful." Some also commented on the realism of this presentation mode: "The outside reality is mapped very well" (participant 6); "the realistic presentation of the outside road increased my feeling of safety" (participant 48). Overall,

it seemed that the sharing of the "robo-driver's reasoning" was seen as best realized by the AR-view: When asked to justify her preference choice for the AR view, participant 66 mentioned that AR made the vehicle's situational awareness most transparent. Another mentioned reason for AR-preference was the lower cognitive effort participants experienced: "It is easier to think in pictures, as opposed to reading or interpreting matchstick men! (participant 2)"; "the presentation was easiest to comprehend quickly (participant 10)." Similar to the iconic presentation mode, universal comprehensibility was mentioned as a plus when compared to text: "No knowledge of a specific language is required" (participant 38). Also, the fine adaptations of the recognition on the scene provided a feeling of safety, such as the fitting of the superimposed trajectory to the road curve. A potential reason for the slightly lower ratings for AR right after having watched the videos was the coloring used for the rectangles marking important elements in the traffic (blue), which was not easily noticeable (compare screens at Figure 5). Some critical comments were related to concerns about information overflow (e.g., "what will this look like when there is more traffic on the road?").

The most commonly mentioned reason behind negative participant ratings and comments was the lack of transparency what the bus would actually do in the next step in the case of pure AR or icon-based communication. In these cases, participants often proposed a combination with textual information to achieve greater clarity. For example, participant 46 stated that "it was very clear that the pedestrian had been recognized. However, the system should inform the passenger that the bus will be braking accordingly". When participants were asked to specify their most preferred alternative, AR was chosen most often (29 participants, i. e. 40 %). However, only 12 of these statements were clear-cut preferences – the rest mentioned not to have a strong preference or recommended to combine AR with other types of information that better explain the next actions of the bus.

3.2.3 Influence of Scenario

There was a main effect of scenario on both helpfulness (diff = 0.74, F(1,71) = 6.37, p = .014) and trust (diff = 0.74,F(1,71) = 11.97, p < .01), and a marginally significant effect on the preparedness to press the stop button (F(1,71) =3.92, p = .05).

In all of these cases, the investigated dynamic passenger information was rated better in the braking scenario than in the turning scenario. For comprehensibility, no significant difference was found.

4 Discussion

The results relating to our first research question on general passenger needs and requirements for mounted screens in autonomous buses (RQ1) imply that passengers would like to be provided with awareness and intent cues and would benefit from them. We conclude that awareness and intent information should be offered in combination with traditional passenger information like upcoming bus stops, remaining travel time and potential critical traffic events. With regards to screens placement, we suggest two screens that are placed on top of the front and rear side windows (at least for minibuses). We also obtained first indications that older users might be more in need of such screens than younger ones. However, this needs further investigation in follow-up trials specifically designed for investigating the role of age in the reception of awareness and intent communication.

Our results related to the question of suitability of scenarios (RQ2) suggest that awareness and intent communication can be realized efficiently for situations where the vehicle reduces speed due to a recognized obstacle on the road. In contrast, in situations where people are to be reassured about route awareness and intended turning, people tend to have less trust in vehicle behavior and perceive dynamic information screens as less helpful. However, this result shall not be over-interpreted: it is only confirmed for situations where the bus does not completely follow passenger expectations, such as making a relatively late turn on a road. In less challenging situations when the bus behaves in a more expected way by turning early, confusion might be lower (but passengers might also require reassurance not as strongly).

The comparison of design elements for screen-based awareness and intent communication (RQ3) resulted in a large variance of reported experiences and preferences across participants that pointed to different strengths and weaknesses of the 3 elements. Consequently, none of the design elements we investigated should be abandoned a priori when it comes to screen content development. Instead their complementary strengths should be recognized and used in combination whenever possible. These strengths are (1) capabilities of AR to mediate a sense of the vehicle's situation awareness, (2) low cognitive load and culture barriers of iconic communication, and (3) text to

provide clear indications of intent with regards to the vehicles imminent actions.

From our experience it seems, that AR is the most sensitive and challenging aspect with regards to design. This starts with seemingly mundane issues, such as the right color for the marking of critical objects, which might differ between different scenarios: while the blue color chosen in the turning scenario was sufficiently noticeable but not overly distracting, it was not catchy enough to highlight the recognized obstacles in the braking scenario. With regard to the use of iconic elements, design solutions should be developed for situations without critical issues. This way the screen is never 'underloaded'.

Designers should take advantage of AR's capabilities to mediate a sense of the vehicle's situation awareness and object recognition, probably by only marking the most critical elements. If an upcoming turn may feel unexpected or abrupt for passengers (as in the turning scenario of Study 2), it is important to also use a visible turn icon and not rely only on AR, thereby leveraging the already familiar design language of existing in-car navigation systems.

Also, the proverbial intuitiveness of icons needs to be thoroughly tested as well as the timing of their presentation within animated sequences. The problem of exposing first-time users to potentially confusing "empty screens" might be alleviated in a natural way by combining awareness cues with traditional information on routes and travel times.

Reflecting on the test methodology and study setup used, the use of public scientific events to conduct studies on first time experiences of a real autonomous bus proved to be well suited to our purpose. In terms of recruiting, the events provided fast and efficient access to large numbers of study participants with a broad demographic range. Also, since participants were genuinely interested in the topic and were already present at the site, there was no need to provide monetary incentives. Furthermore, using a real bus proved not only to be helpful in attracting an audience, but also in providing a captivating environment (as was necessary for avoiding distractions and dropouts during the test sessions) as well as a highly realistic study setting (as required for external validity).

Considering (potential) drawbacks, linking a user experiment to a public event creates some inflexibilities since study execution is tied to specific times and locations as dictated by the event organization. This results in additional pressures on study preparation compared to traditional lab studies where in case of e.g. technical problems study execution schedules can be postponed. Furthermore, like in field trials, experimenters face risks stemming from a lack of control over location and context

factors (e.g. noise, light situation, power supply, and internet access). Thirdly, event visitors have a much more constrained time budget (typically 5-20 minutes) for participating (mostly ad-hoc) in a study given the presence of other competing attractions at the site. This relatively short session time limits the scope and depth of a study conducted under such circumstances. These limits can be partially addressed by study design choices such as utilizing between-subjects designs. For these reasons, performing user experiments in the context of public events should not be seen as general replacement for lab or field studies, but - after taking aforementioned benefits and risks into account - rather as a supplemental, particularly when the investigation is of exploratory nature.

5 Conclusions and Outlook

In this article we investigated future passengers' needs and requirements for screen-based awareness and intent communication in autonomous buses. To this end, we presented the results of two user studies with first-time users, conducted with a state-of-the-art autonomous bus at public demonstration events. The results of the first study show that after having ridden an autonomous bus for the first time, a large portion of test participants confirmed the need for dynamic information screens for awareness and intent communication in the context of autonomous public transport. Our second study, in which participants were confronted with different simulated driving scenarios and design alternatives, indicates that awareness and intent communication in autonomous buses may be required for indicating exceptional situations (like potential hazards), but not so much for indicating route directions. In addition, we found that none of the three compared modes of visual communication (text, icon and AR) should be used in isolation. The main reasons are that user preferences are too diverse and these modes tend to complement each other rather than to meet both awareness and intent communication requirements on their own. Our results provide guidance on how to best combine these modes, how to extend them with further design elements and which further research directions to pursue.

To our knowledge, our two studies are the first ones targeting real-time screen-based awareness and intent communication in autonomous buses, and as such they should inspire further research in this promising field. As is typically the case for such early studies, the study setup imposed several limitations that need to be taken into account for result interpretation and the planning of future

research. First, we did not investigate the whole design space, but deliberately focused on passenger information screens mounted within the vehicle because of their prevalence in buses, their capabilities of offering optional and uncritical background awareness, as well as the high expressiveness of multimedia content. Nevertheless, followup studies are encouraged that close this gap by investigating other communication devices and modalities, such as virtual avatars [10], auditory and vibro-tactile warnings, ambient displays, or passengers' own devices with regards to directing attention to a foreground event or task [22], mediating emotional qualities [14] or providing ubiquitous awareness [16].

Secondly, our two studies only covered a small subset of the large range of scenarios in which awareness and intent communication is potentially relevant such as a pedestrian suddenly crossing the street (with the bus braking) or the bus overtaking another vehicle (with the bus speeding up). We consider this an unavoidable limitation, since the focus of our (time and resource constrained) experiments was on evaluating different design elements for awareness and intent communication (in the context of two representative scenarios) with users and not the exploration of various driving situations and scenarios. Nonetheless, we see the latter as an important focus of complementary studies as part of future work.

Thirdly, our studies only touched the surface of trust and related concepts. Future studies on this topic should take the presented studies as encouragement and inspiration to investigate trust aspects more systematically, including the development of personalized trust models [27], adapted technology acceptance models, as well as measurement methods beyond self-reporting of potential behavior (e.g. the number of actual emergency button presses). Furthermore, exploiting public demonstration events (which typically offer a large demographic variety) as a means to enable and investigate first-time exposure to new technologies appears as a useful strategy to "test the waters" before any large-scale roll-outs. However, this needs to be complemented by in-depth studies that look at specific aspects such as the influence of user diversity, as well as longitudinal field trials that feature the investigation of everyday usage patterns and longer driving exposures.

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