A mobile application for resolving bicyclist and automated vehicle interactions at intersections*

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Abstract— **In order to facilitate safe interactions between automated vehicles (AVs) and vulnerable road users (VRUs) such as bicyclists, we present a communication application for mobile devices that allows an AV or its passenger and a bicyclist to interact in certain traffic scenarios. At the intersection, the AV or its passenger can change the existing right-of-way rules to prioritise the ego-vehicle or the bicyclist. In a coupled driving simulator in which these two road users can interact, 16 proof-of-concept experiments are conducted. It is found that the perceived safety at conflict points can be increased through the use of the application. An investigation of the user data provides insights into the AV passengers' decision types and duration in the scenarios studied. Moreover, the simulation results are used to revise and further develop the application concept.**

I. INTRODUCTION

In the transition towards sustainable urban traffic, two trends can be recognised: increasing automation of motorised vehicles, and promotion of pedestrian and bicycle traffic [1], [2], [3]. In today's road traffic, pedestrians and bicyclists communicate with drivers of motorised vehicles for instance via hand gestures and eye contact [4]. With increasing vehicle automation, novel communication methods are made possible which facilitate safe interactions between automated vehicles (AVs) and vulnerable road users (VRUs) such as pedestrians and bicyclists. One such method is the development of innovative human-machine interfaces (HMIs). Despite many studies in the field of HMI development, the vast majority have been dedicated to car-pedestrian interaction [5], [6]. Since bicycle traffic is an important part of the development towards sustainable urban transport as well, here we will examine and address car-bicyclist interaction. Communication can provide a vehicle with additional information to supplement the inputs from its on-board sensors, for example to extend the driver's or vehicle's field of vision and thus further increase safety in road traffic [7]. In this paper, we present a mobile application for human-machine and vehicle-to-infrastructure (V2I) communication. The concept is tested in a virtual environment with a coupled bicycle and automated vehicle simulator. Based on the simulator results, we evaluate the behaviour of test subjects using the application and reach conclusions regarding the acceptability of the proposed solution for resolving traffic interactions as well as assess the effects on traffic efficiency, safety and user acceptance.

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II. STATE OF THE ART OF HMI CONCEPTS FOR AUTOMATED VEHICLES AND BICYCLISTS

External HMIs (eHMIs) play a major role in automated vehicles in recent HMI research. They are devices which are mounted on the outside of the vehicle and are used to communicate the driving state to human road users. There are several studies that investigate the best ways to convey this information, but, so far, no definitive answer has been found. In one study, for example, lights and sounds are found to be preferred over text messages [8]. According to another study, text is the most understandable form of communication [9], [10]. Since there is a lack of a standardised evaluation procedure for eHMIs, the comparison of different studies is often not meaningful [5]. In a first step to address this issue, a unified taxonomy for improved and systematic comparison of eHMI design is created, and 18 dimensions of eHMI design are defined, such as the color choice or communication modality (visual, auditory, haptic, body language) [6]. This taxonomy is derived from eHMI concepts, but is also a useful basis for developing other HMIs. In addition to the external communication of an AV, internal communication with its passengers is a crucial point [11]. The main component in communicating the automated vehicle behaviour is the automation HMI (aHMI). In doing so, the aHMI should adapt to traffic events and the passengers' information needs and status, aiming to increase trust, acceptance and safety of the system. The most important component of the aHMI is the visual element, due to a higher information rate compared to auditory or haptic signals. Therefore, the instrument cluster in the windshield or a monitor on the center console is used. Also established are head-up displays (HUDs), optionally employing augmented reality [12], [11].

One criticism in current HMI research is that the interaction of some road users is studied much more intensively than other user groups [6]. In particular, car-bicycle interaction is highly neglected in current HMI design research. The existing on-bicycle HMIs can be structured in haptic, auditorial and visual HMI types. The only investigated haptic HMI is handlebar vibration [13], [14]. Because of the low distraction from the traffic events, vibrations are preferred over visual feedback in [13], with the drawback of only basic information possible to communicate. Auditory interfaces as mentioned in [14] with helmet audio, verbal and nonverbal information. The effectiveness of audio interfaces in real world traffic scenarios is questionable, because of the possibility of distracting environmental noise and clarity when many traffic participants interact. Visual AV-bicycle interfaces are laser projections on the road surface, eHMIs on AVs and bicycle HUDs [14], [15], [16]. The only on-bicycle system is the bicycle HUD. It helps the cyclist to keep track of nearby vehicles using arrows and distance indicators [14]. On-bike HMIs are found to fulfil the bicyclist's information needs, but can in contrary be a barrier to cycling, because of increasing cost and complexity of the traditional bicycle [17]. Within this paper we describe a communication solution with visual and auditory elements to further investigate on-board HMI systems for both, AVs and bicycles.

III. METHODOLOGY

A. Simulator Study

To assess the proposed communication concept, the application was tested in a simulation with coupled driving simulators for a bicyclist and an AV (Fig. 1). 16 study runs were performed with two subjects each (13 female, 19 male - Age group *18-24*: 12, *25-39*: 19, *40-59*: 1). During the simulation, both test subjects interact in the same virtual environment. The AV model - a compact car - drives automated. Its passenger is informed about the automation and vehicle state with the HMI using a tablet, simulating a dashboard infotainment system. The bicyclist can ride freely in the virtual environment and is guided through the virtual city by instructions in a mobile application running on a handlebar-mounted smartphone. The bicycle simulator allows the test subject to control the bicycle speed and steering angle [18]. Also, hand gestures of the bicyclist are detected and animated in the simulation.

Both participant routes intersect at certain points. At these points, the study scenarios take place, whereas the right-of-way is regulated by the application. In the investigation scenario, the bicyclist intends to turn left, crossing the path of the AV, which is approaching the intersection from the opposite direction and continuing straight (Left Turn scenario). A main focus and innovation in this research is the investigation of the possibility of changing the prioritization rules at the intersection. The future adoption of automated driving in urban traffic has the potential to expand the means of regulating traffic in urban networks. It is often already the case in conventional traffic, especially at unsignalised intersections, that human drivers yield their right-of-way to other road users for multiple situational reasons and primarily for resolving complex traffic situations. Reducing the probability of the emergence of complex traffic situations on the road is a critical factor for the widespread adoption of automated driving, since, in cases where automated vehicles are not able to resolve such situations, the vehicle control has to be handed over to the vehicle passenger or a remote control center operator that has to resolve the deadlock situation. Thus, in this research we want to investigate and understand how future AV passengers reach their decisions and regulate priority and assess the acceptability of this decision-making both from the AV passengers' and the bicyclists' perspectives. Therefore, in the simulation there are three different ways in which priority is determined.

1) Default: The common priority rules apply. The bicyclist is subordinated in relation to the AV. The application displays navigation information.
2) AV: The automated vehicle decides and enforces the priority rules. The bicyclist and the AV's passenger are informed about the chosen traffic rules.
3) AV passenger: The passenger decides if the bicyclist is given priority. The bicyclist is informed about the decision.

In certain scenarios, the HMI displays additional information to the AV passenger on whether the decision influences the traffic flow in a positive or negative way (Left $\text{Turn}_{\text{+Info}}$ scenario). We can therefore investigate whether the study participant decides differently in this case compared to the case where no additional traffic information is provided. In addition to the decision type, the duration required for the users decision is analysed. We aim to investigate not only the right-of-way decisions, but also the question of whether the bicyclist trusts (1) the application will display correct information, and (2) the AV will decelerate or stop when the displayed message announces it. To gather this data, the test subjects fill a short survey right after each study scenario and at the end of the simulation study.

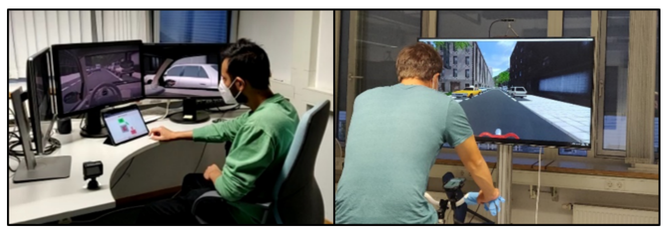

Fig. 1. Coupled driving simulator with mobile devices as HMI components. AV simulator (left), Bicycle simulator (right)

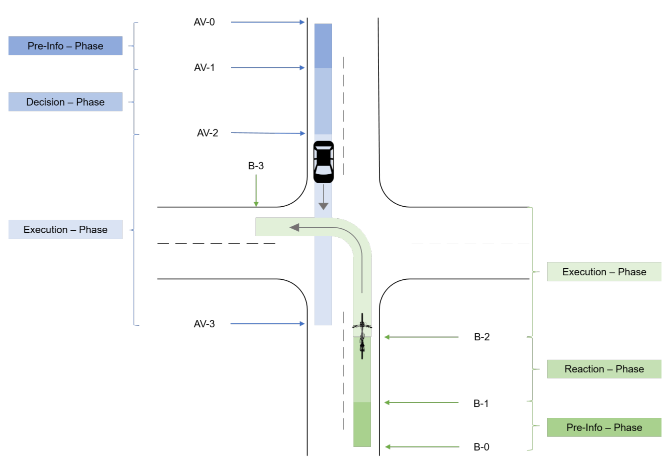

Fig. 2. Procedure during a study scenario

B. Scenario Design

In between study scenarios, the bicyclist is guided through the virtual city via navigation instructions from the application, and the AV passenger receives information about the navigation of the car. If they reach a default scenario, the application remains in navigation mode. Upon entering one of the other study scenarios, the following procedure applies (Fig. 2). The AV passenger first gets preliminary information on which traffic scenario is coming up, followed by a screen prompting them to make a decision about the traffic rules if necessary. After confirming the decision, the passenger receives information about the vehicles behaviour. In the scenarios in which the AV makes the decision, its passenger is simply informed about the vehicles behaviour.

The bicyclist also receives the preliminary information about the upcoming scenario. After the decision is made by the AV or its passenger, the bicyclist receives information on whether it should accelerate or decelerate and which traffic participant is prioritised in the conflict situation. It is important that the cyclist has sufficient reaction time to perform the manoeuvre after a right-of-way decision. The amount of information a bicyclist can process when quick reaction is required is reduced. Therefore, the application should have as little influence on the remaining attention of the bicyclist in the traffic situation as possible. This is achieved by simplifying pictorial information in comparison to the AV-passenger's display and by the strategic use of color (Fig. 3 and 4).

C. HMI Design

In order to make the screen displays as comprehensible and user-friendly as possible, we rely on existing design concepts. Especially important are the communication modality and the color scheme. Since the HMI hardware in the simulator study are a smartphone and a tablet, the number of communication modalities is limited. Because the device is not worn on the body, haptic information perception is omitted, leaving only the visual and auditory information channels. Auditory signals are used to alert the human HMI-user about new information or a required intervention. In particular, the bicyclist should not have to continuously look at the smartphone screen, distracting them from the surrounding traffic.

The visual information on the HMI consists of three parts: text, image and color scheme. Text is considered the most unequivocal way of encoding information [5], [10]. Moreover, even the criticism of the language barrier for text messages can be neglected, because an application for mobile devices is usually available in multiple languages, as it is in our concepts [10]. From many eHMI concepts, the text messages used are very short [5], [10], [12]. However, to describe complicated traffic situations unambiguously, longer text passages were necessary and so text is not suitable. That is why for the representation of traffic situations image form is chosen. In addition to text and images, colors are also used to encode the current information. By means of examples, this coding is explained below in more detail.

In part 1 of Fig. 3, the HMI provides the AV passenger with information about upcoming manoeuvres of the vehicle and navigation information. In part 2, the preliminary information of a left turn scenario can be seen. The two road users are shown as blue icons. In addition, the intended direction of travel is marked with arrows, and a yellow triangle is displayed as a warning at the point of conflict. Yellow is also used as a bar color in order to attract the attention of the HMI-user. The bottom bar also contains real-time information, indicating the distance in meters to the conflict point. Fig. 3 part 3 shows the screen display that the AV passenger must use to make a decision. Compared to the previous information, the icons of the vehicles are now colored red or green. Analogous to the colors at traffic lights, red stands for stop or delay and green for proceed. This is additionally clarified by arrows indicating the direction of travel and the intention to accelerate. By simply clicking on the icons you can change the right of way. The colors and arrows adjust so that you get a preview of the upcoming scenario. In part 3 of Fig. 3, the distance in meters to the conflict point is also shown in real time to give a sense of how much time is left for the decision. Blue was chosen as a neutral bar color so as not to distract from the decision making [19]. With the 'OK'-button, one can finally confirm their decision. If necessary, it is also indicated via text whether the decision has a positive or negative effect on the traffic quality. In part 4 (Fig. 3), the information about the current or planned behaviour of the vehicle is displayed. The vehicle icons are red or green depending on the decision, with corresponding directional arrows. In this example, the bar color is green because the AV has the right-of-way. If the decision were reversed, the bar color would be red. In addition to the bar color, a text message about the current right-of-way rules is displayed along with a hint that the cyclist has been informed. As mentioned above, in some scenarios, the AV decides, and the screen display in part 3 (Fig. 3) is not used.

The color scheme and signs for the bicyclist are analogous to the screens for the AV passenger. In part 1 in Fig. 4, the navigation is shown, and in screen part 2, the preliminary

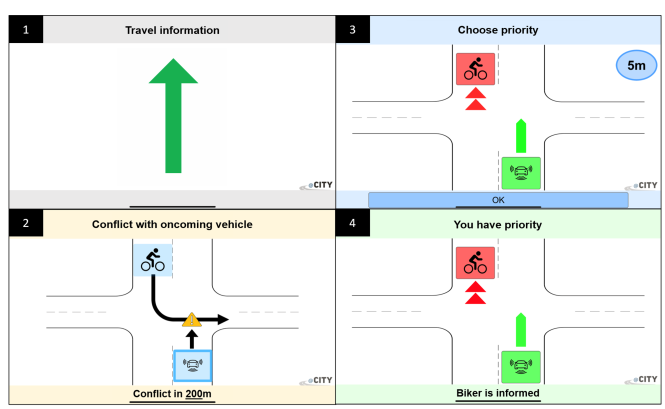

Fig. 3. Different screens of the communication application for the AV passenger

information. It is the same traffic situation as in Fig. 3 from the cyclist's point of view. The user's own vehicle is always shown at the bottom, so that the direction of the arrow corresponds to the direction of movement in the simulation. Sections 3 and 4 in Fig. 4 show the instruction to the cyclist after the AV or its passenger has decided about the priority rules. A text with a self-centered instruction is displayed at the top and the right-of-way below. The right-of-way information is also imparted using the background color red or green depending on the right-of-way, supported by arrow symbols.

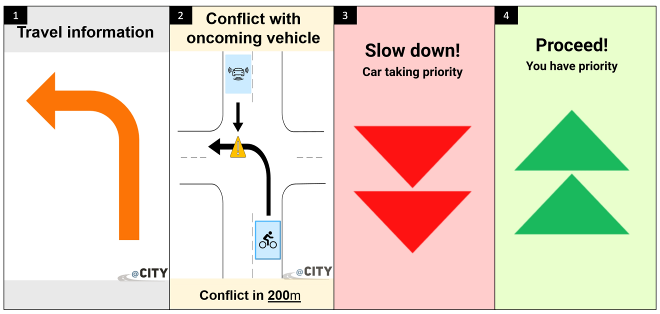

Fig. 4. Different screens of the communication application for the bicyclist

To direct the bicyclist's or passenger's attention to the HMI-screen, non-verbal audio signals are used. We apply two different audio signals: an information signal and a warning signal. The information signal is used for navigation; the warning signal whenever a scenario is imminent or when the subject's intervention or attention is required. By using an audio signal for a specific purpose e.g. as a warning signal, the application can provide clues about the upcoming situation without having already processed the visual information.

IV. RESULTS

A. Right-of-way decision duration and type

When making right-of-way decisions using the application, the decision duration of the AV-passenger is of particular interest. Furthermore, the frequency of a decision type is analysed. A total of 50 decisions are analysed separately by scenario (Fig. 5). It can be seen that the median decision duration in the Left Turn scenario is 3.99 seconds. For the Left Turn$_{\text{+Info}}$ scenario, where information is provided about the influence of the decision on the traffic situation, the median decision duration is significantly higher, at 9.25 seconds (Wilcoxon ranksum test, $z = -4.92$, $p < 0.001$, $\alpha = 0.01$). This fact indicates that the additional information for the AV passenger results in a longer decision time. When analyzing the data, it is still important to note that the users of the communication application are not trained in accomplishing this task. If the users are more familiar with the concepts and the decisions to make, decision duration is expected to decrease. It is also expected that additional information about the traffic situation are perceived as similarly complex and the decision duration in the Left Turn and Left Turn$_{\text{+Info}}$ no longer differ significantly.

In addition to the decision duration, the number of the priority decisions made for each vehicle type is analysed. The AV-passenger can choose to either keep the priority or to hand it over to the bicyclist. The data is shown in Fig. 6. In total, the AV passenger prioritises himself in 43 cases and the bicycle rider in 7 cases. Inspecting the scenarios individually, the numbers deviate strongly from the average value. In the Left Turn scenario without additional information, the AV passenger prioritises himself in 16 of 23 cases. This value is quite plausible because, as can be seen from the scenario description, the existing priority rules are not changed with this decision. The data for the Left Turn$_{\text{+Info}}$ scenario shows a different picture. Here, the AV passengers prioritise themselves according to the existing right-of-way rules 100% of the time. On the HMI screen, this decision indicates that the traffic situation is worsened. It should be noted that there was only the AV and the bicycle in the test environment and no surrounding traffic. If the information is not only displayed on the HMI screen, but is also apparent from the traffic situation in the simulation, the decision trend of the AV passenger might have been different. Traffic management systems often act proactively in an effort to preserve a particular traffic state in the road network, meaning the traffic state at a specific network location might appear normal, however upstream or downstream of this location a different situation might unfold. This would of course not be obvious to the AV passenger. Despite the fact that the AV passenger is explicitly informed that not prioritizing the bicyclist will lead to a deterioration of the traffic state, the AV passengers - perhaps not trusting the system - may choose to prioritise themselves at the intersection. The results of such a decision making indicate that future autonomous vehicle systems aiming for system-optimal traffic flow rather than a user equilibrium should overtake the decision-making in such situations and not rely on soft 'nudges' towards the desired behaviour.

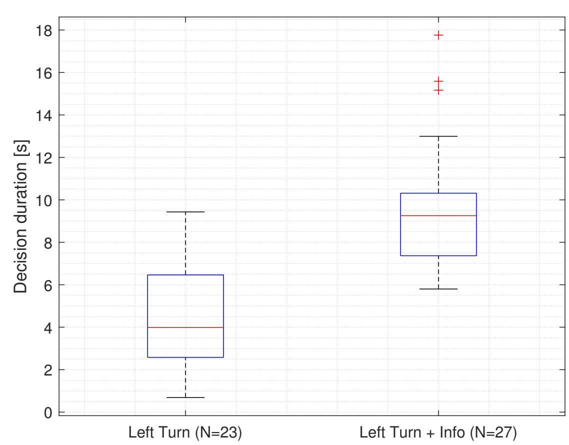

Fig. 5. Right-of-way decision duration of the AV-passenger at investigation scenarios

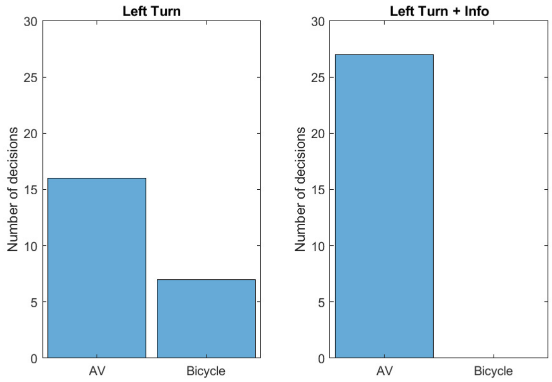

Fig. 6. Right-of-way decision type of the AV-passenger at investigation scenarios

B. Subjective safety perception with and without application usage for right-of-way decisions

The subjects drive through the virtual city area, and the decision-making instance (AV passenger, AV, default) changes in a specific order based on the study scenarios. After each study scenario, the subjects are asked about the previous conflict situation. One question is designed to evaluate the perceived safety in the scenario (Question to AV passenger: ‘Did you have the feeling that you endangered the cyclist?’; to the bicyclist: ‘Did you have the feeling that you were endangered by the car?’). To evaluate the performance of the application, the survey is analysed separately for situations when the application is in use for managing priority rules and when no information about the upcoming scenario is provided.

Fig. 7 shows the analysis of safety perception separated according to vehicle type. The subjects can evaluate the safety level from 1 (not at all) to 5 (yes, absolutely). One can see clearly that subjects feel safer at conflict points with the application in use, with a significantly deviating value for bicyclists (Wilcoxon ranksum test, $z = -2.35$, $p < 0.019$, $\alpha = 0.05$). The mean value of the safety evaluation is 0.7 points higher without the app for the AV passenger and 1.0 points for the bicyclist. Consideration must also be given to how clear the instructions of the application were, in order to isolate the perceived safety loss caused by not understanding the instructions of the application. Therefore, the subjects are also asked how clear the instructions of the application were. Fig. 8 compares the clarity of instructions at conflict situations with and without the app, again separated according to vehicle type. The subjects can evaluate the clarity of instruction from 1 (very bad) to 5 (very good). The mean value differs significantly with and without the application in use for the AV (Wilcoxon ranksum test, $z = -3.93$, $p < 0.001$, $\alpha = 0.05$). The bicyclists rate the clarity without the app about the same, only 0.4 points less, the AV-passenger 1.5 points less. The lower clarity of instructions has an influence on the perceived safety in a situation. One reason for the bad rated clarity of instruction is that subjects misunderstand the navigation arrows as a priority sign. Therefore, a green arrow that indicates ‘go straight’ is understood as ‘you have priority’, like discussed in the exchange with the test subjects. This misunderstanding also leads to a lowered feeling of safety, because the other road users of course do not behave in a manner consistent with this false interpretation of the information provided by the application.

Despite the findings above, it can be argued that the goal of the application, i.e., to reduce the amount of hazardous traffic situations, is fulfilled. The misunderstandings of an instruction of the application by a subject reflects the situation when a road user is not able to perceive the upcoming traffic situation correctly. To reduce such misunderstanding, the design of the application should be further revised.

C. User experience with the mobile application

After the whole simulation study, the test subjects were asked to evaluate the overall user experience. It is important to know how helpful or practical the users rate the application before deploying the design concept in the real world. Also

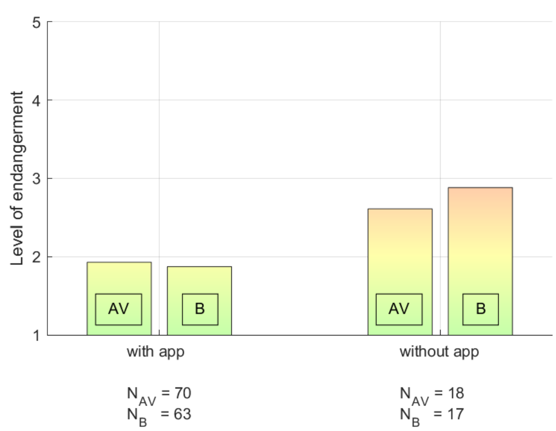

Fig. 7. Subjective safety perception with and without application usage for right-of-way decisions at conflict situations

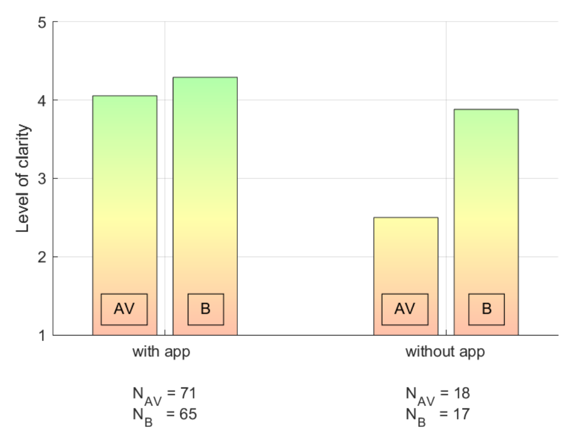

Fig. 8. Clarity of instructions with and without application usage for right-of-way decision at study scenarios

important is, as mentioned earlier, the trust in the instructions and the behaviour of other road users. In Fig. 9, these four issues are addressed. The result of the helpfulness (Bicycle: 3.6 points - AV 3.7 points) and practicability (Bicycle: 3.9 points - AV 3.6 points) evaluation tends to be positive. A slightly increased value can be noticed in the practicability for the bicyclist. The question of trust is split into two aspects: trust in the application instructions, and trust that other road users will behave as indicated in the application. In both cases, a positive trend is observed. The passengers rated the trust in both cases with average 3.1 points; the bicyclists with 3.4 towards other road users and 3.9 points towards the instructions. The trust of the bicyclist towards the application instructions is higher than that of the AV passengers, with a difference of 0.7 points.

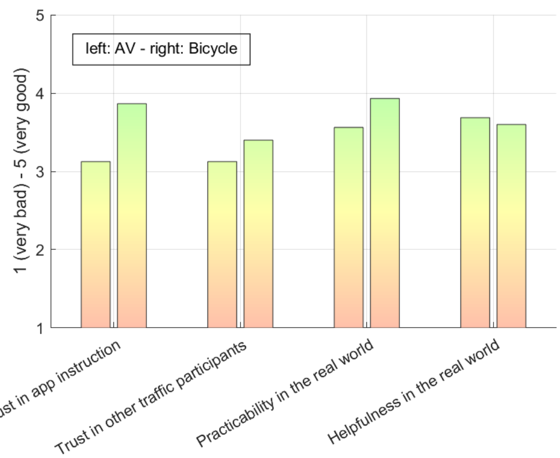

Fig. 9. User experience with the mobile application

With regard to the use of the application in practice, the bicyclist rating is especially important. Compared to the AV passenger, the bicyclist must use an additional device. In AVs, different HMI components are already built in. The goal of the application is to increase the safety of VRUs and provide a platform for the interaction with AVs. Therefore, the application must be easy to use and offer an increase in safety in order to motivate the VRU to actually use the application. Frequent use and positive experiences are also expected to increase trust towards the application.

V. LIMITATIONS

The applicability of the presented communication application is limited in several points. While inside the cockpit of an AV, HMI devices are integrated in the future [11], it cannot be assumed that every bicyclist is willing to use a mobile phone. Despite the trend of modern electric (cargo) bicycles models with integrated HMI screens, the presented communication application should be seen as safety extension. Another limitation is the number of involved traffic participants in the considered scenarios. The experiments were conducted with only two participants AV and bicycle. In crowded urban areas the applicability of the concept has to be investigated and compared to other communication methods. Nevertheless, for certain use cases e.g. situations with limited view, this concept is still promising. The main drawback of the study results is the small sample size. For more reliable results, more experiments must be conducted. Also the composition of the sample collective is not representative, because mainly students within younger age groups took part. Besides the unavoidable issue of driving simulator validity regarding safety perception [20], especially the bicyclists field of view was with a single monitor fairly restricted, which can impact the subjective safety perception.

VI. CONCLUSIONS

An application for mobile devices for the communication and cooperation between a bicyclist, an AV and its passenger is developed and was investigated in current state. Its main purpose is to increase the safety at interaction points and contribute to acceptance and trust towards automated driving for both the bicyclists and the AV passengers. It is found that the average right-of-way decision duration of the AV passenger is 3.99 seconds. Additional information for influencing the AV passenger decision in a specific direction can increase the decision duration significantly for untrained users. The decision made corresponds in the majority of cases to the existing traffic regulations. Moreover, the subjective safety perception is increased when using the application. It is recognised that the differentiation between navigation and traffic-regulating HMI instructions is not clear enough and must be improved. The overall user rating of the application indicates a positive helpfulness and practicability in real world. With more frequent use, an increased trust in the applications instruction and in the behaviour of other vehicles corresponding to these instructions is expected.

The application is still in an early development stage and is being further developed. In addition to the required improvement in providing a clearer distinction between navigation and right-of-way instructions, the following points will be addressed during the revision process:

- Usability for every device: The test subjects should be able to use their own mobile devices in the simulation so they can better evaluate the application in terms of practicability.
- Dynamic scenario information: For easier understanding of the traffic situations, the largely static displays of the application are supplemented by dynamic elements. This can be, for example, the real-time position of vehicles approaching the conflict point. One issue will be to find a balance between very detailed visualisation and simple and fast comprehensibility.
- Accessibility: Adaptation to people with color vision deficiencies. The design of the application needs to be improved in terms of color selection.

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REFERENCES

[1] A. Mahdavian, A. Shojaei, S. Mccormick, T. Papandreou, N. Eluru, and A. A. Oloufa, "Drivers and barriers to implementation of connected, automated, shared, and electric vehicles: An agenda for future research," *IEEE Access*, vol. 9, pp. 22 195–22 213, 2021.

[2] J. Pucher, C. Komanoff, and P. Schimek, "Bicycling renaissance in north america?: Recent trends and alternative policies to promote bicycling," *Transportation Research Part A: Policy and Practice*, vol. 33, no. 7, pp. 625–654, 1999.

[3] C. European, "The european green deal," https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52019DC0640, 2019.

[4] B. Färber, *Communication and Communication Problems Between Autonomous Vehicles and Human Drivers", bookTitle="Autonomous Driving: Technical, Legal and Social Aspects*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2016, pp. 125–144.

[5] A. Rouchitsas and H. Alm, "External humanmachine interfaces for autonomous vehicle-to-pedestrian communication: A review of empirical work," *Frontiers in Psychology*, vol. 10, 2019.

[6] D. Dey, A. Habibovic, A. Lcken, P. Wintersberger, B. Pfleging, A. Riener, M. Martens, and J. Terken, "Taming the ehmi jungle: A classification taxonomy to guide, compare, and assess the design principles of automated vehicles' external human-machine interfaces," *Transportation Research Interdisciplinary Perspectives*, vol. 7, p. 100174, 2020.

[7] H. Fuchs, F. Hofmann, H. Löhr, and G. Schaaf, "Car-2-x," in *Handbuch Fahrerassistenzsysteme*, 2015.

[8] N. Merat, T. Louw, R. Madigan, M. Wilbrink, and A. Schieben, "What externally presented information do vrus require when interacting with fully automated road transport systems in shared space?" *Accident Analysis & Prevention*, vol. 118, pp. 244–252, 2018.

[9] C.-M. Chang, K. Toda, T. Igarashi, M. Miyata, and Y. Kobayashi, "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*, ser. AutomotiveUI '18. New York, NY, USA: Association for Computing Machinery, 2018, p. 104109.

[10] P. Bazilinskyy, D. Dodou, and J. de Winter, "Survey on ehmi concepts: The effect of text, color, and perspective," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 67, pp. 175–194, 2019.

[11] K. Bengler, M. Rettenmaier, N. Fritz, and A. Feierle, "From hmi to hmis: Towards an hmi framework for automated driving," *Information*, vol. 11, no. 2, 2020.

[12] Y. Forster, F. Naujoks, and A. Neukum, "Your turn or my turn?: Design of a human-machine interface for conditional automation," *Proceedings of the 8th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 2016.

[13] M.-C. H. Oczko, L. Stratmann, M. Franke, J. Heinovski, D. S. Buse, F. Klingler, and F. Dressler, "Integrating haptic signals with v2x-based safety systems for vulnerable road users," in *2020 International Conference on Computing, Networking and Communications (ICNC)*, 2020, pp. 692–697.

[14] M. Hou, K. Mahadevan, S. Somanath, E. Sharlin, and L. Oehlberg, *Autonomous Vehicle-Cyclist Interaction: Peril and Promise*. New York, NY, USA: Association for Computing Machinery, 2020, p. 112.

[15] Y. Li, H. Cheng, Z. Zeng, H. Liu, and M. Sester, "Autonomous vehicles drive into shared spaces: ehmi design concept focusing on vulnerable road users," in *2021 IEEE International Intelligent Transportation Systems Conference (ITSC)*, 2021, pp. 1729–1736.

[16] C. Kaß, S. Schoch, F. Naujoks, S. Hergeth, A. Keinath, and A. Neukum, "A methodological approach to determine the benefits of external hmi during interactions between cyclists and automated vehicles: A bicycle simulator study," in *HCI in Mobility, Transport, and Automotive Systems. Driving Behavior, Urban and Smart Mobility*, H. Krömker, Ed. Cham: Springer International Publishing, 2020, pp. 211–227.

[17] S. H. Berge, M. Hagenzieker, H. Farah, and J. de Winter, "Do cyclists need hmis in future automated traffic? an interview study," *Transportation Research Part F: Traffic Psychology and Behaviour*, vol. 84, pp. 33–52, 2022.

[18] A. Keler, J. Kaths, F. Chucholowski, M. Chucholowski, G. Grigoropoulos, M. Spangler, H. Kaths, and F. Busch, "A bicycle simulator for experiencing microscopic traffic flow simulation in urban environments," in *2018 21st International Conference on Intelligent Transportation Systems (ITSC)*, 2018, pp. 3020–3023.

[19] D. Tharangie, A. Irfan, K. Yamad, and A. Marasinghe, "Kansei colour concepts to improve effective colour selection in designing human computer interfaces," *International Journal of Computer Science Issues*, vol. 7, 2010.

[20] J. de Winter and R. Happee, "Advantages and disadvantages of driving simulators: A discussion," in *Proceedings of Measuring Behavior 2012*, 2012.