Key Findings from the Development of a V2X Data Visualization Solution

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ABSTRACT

A decisive factor for effective driver awareness and warning systems is the visualization of important and safety critical information for the driver. In previous work, we introduced a flexible two-component system that can visualize real time data from vehicle-to-x (V2X) communication [1]. In order to maximize the overall performance and reliability, the system consists of a vehicle-integrated V2X communication unit (onboard unit, OBU), and a personal portable device (PPD) which is used for conveying the information to the driver.

The focus of this paper is on the application running on the PPD. The mobile application supports some of the so-called 'day-one use cases' that are considered to create a sound basis at the beginning of V2X deployment. Based on our experiences during the development and the results from a laboratory user study, key findings are summarized and recommendations for the design of a V2X-based visualization solution are given. The main aspect of our examination is the human-machine interface. Specifically, the user interface, text-to-speech support, mode of warning presentation and selection of itinerary-related information are considered.

Keywords: Vehicular ad-hoc networks (VANETs), vehicle-to-x (V2X), visualization, smartphone.

1. INTRODUCTION AND BACKGROUND

For the success of vehicle-to-x (V2X) communication-based applications, it is important to provide a well-designed human-machine interface (HMI) that reliably supports and extends the traffic awareness of the driver. However, up to now most researchers in this domain still focus on technology aspects and tend to neglect the human-computer interaction. If the driver is not aware of the additional information, the area of application is limited to tasks that can autonomously be taken care of by the vehicle.

In order to overcome this shortcoming, we have designed a V2X solution that allows for rapid evaluation of visualization concepts on state-of-the-art personal portable devices (PPDs) in previous work [1]. The two-component V2X communication system consists of a vehicle-integrated V2X communication unit (onboard unit, OBU) and a PPD, such as a smartphone or tablet PC. Based on an optimized work split with an efficient message exchange and processing system, the PPD can access V2X data, such as periodically broadcasted speed and position of nearby vehicles (awareness messages), or event driven notifications about nearby traffic incidents (e.g. hazardous location or emergency braking).

In this work, we focus on the application *DriveAssist* [2] running on the PPD, responsible for conveying the information to the driver. Based on our experiences, gathered during the development and testing, and on the results of a laboratory user study, we summarize key findings and give recommendations for the design of a V2X communication-based driver awareness application.

The paper is structured as follows: We start with an overview on related work in Section 2. In Section 3, we introduce *DriveAssist*, our V2X-based driver assistance system for the Android platform. The performed user study is described in Section 4, and its results are presented in Section 5. By discussing the results, we formulate recommendations for the development of V2X visualization systems in Section 6. In Section 7, we conclude our findings and give an outlook on future work.

2. RELATED WORK

The *WILLWARN* system [3] is a wireless local danger warning system based on vehicle-to-vehicle communication. The detection of different hazards is realized by evaluating the information available on the different vehicle buses. The detected hazards are then sent out to the areas of interest. After combining remote and local information, the relevance of the hazards is evaluated by comparing the vehicle's trace and the position of the incident. Finally, a hazard classification rule set decides when and how to inform the driver about a certain incident. The classification algorithm distinguishes between three urgency classes that determine the priority of the warnings: *imminent dangers* (e.g. end of jams), *particular attention* (e.g. difficult road conditions), and *driver information* (e.g. high traffic). The HMI of the *WILLWARN* system consists of a warning screen showing the type of hazard, and a map view with a warning icon. While the *WILLWARN* system focuses mainly on the data acquisition and classification, our investigation concentrates on the HMI.

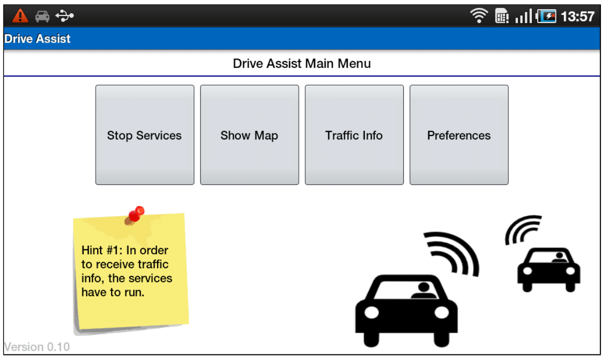
The *CODAR Viewer* [4] is a context information display that visualizes V2X communication data in order to provide additional traffic information. It is part of the *Cooperative Object Detection And Ranging (CODAR)* toolkit [5] which comprises a V2X simulation environment, visualization components, and an algorithm toolbox. The *CODAR Viewer* supports the driver by adequately presenting the current traffic situation and, thus, it allows for more informed driving decisions. In contrast to our solution that supports timed and prioritized warnings, the *CODAR Viewer* is meant for presenting an overview of the current situation.

Besides using a visual representation for creating traffic awareness, auditory [6], tactile [7], and olfactory interfaces [8] have also been explored. Cao et al. [9] have investigated the effect of different modalities for driver warnings. Our application is using a multimodal combination of visual warnings and text-to-speech (TTS)-generated speech cues.

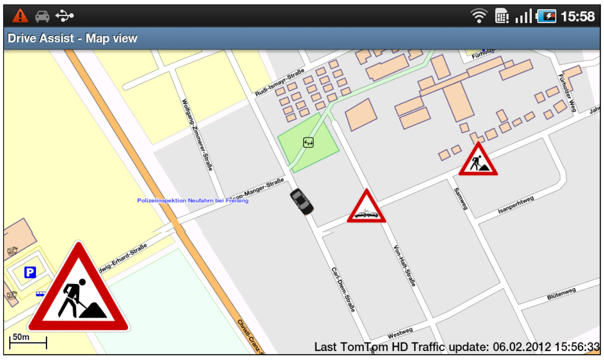
3. THE *DRIVEASSIST* SYSTEM

DriveAssist is our first prototype of a driver assistance system for the Android platform [2, 10]. It is a framework for rapid evaluation of visualization concepts of V2X data. Its main menu is depicted in Fig. 1a. The application offers an active map view (cf. Fig. 1b) for overseeing the vehicle's surrounding and a passive warning screen (cf. Fig. 1c and Fig. 1d) that is triggered by a service running in the background. Besides visual representations, *DriveAssist* also supports text-to-speech (TTS) output.

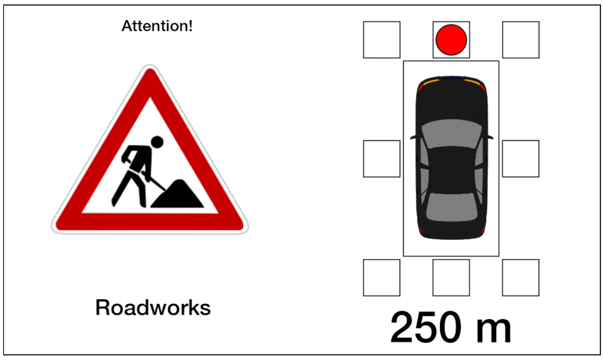
The map view provides an overview for the driver and other vehicle passengers. In Fig. 1b, a possible traffic scenario is depicted. The car is approaching a cross street with a stationary vehicle warning and a roadwork warning. The warnings are displayed as they might become relevant for the driver



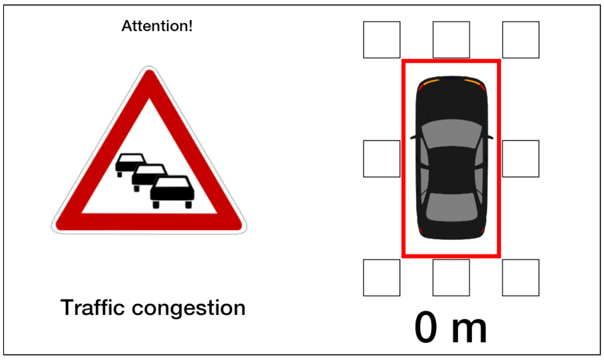
(a) *DriveAssist*'s main menu. The four big buttons in the top row are optimized for in-vehicle usage and allow controlling the central parts of the application. The yellow hint (bottom left) shows short pieces of usage information, when it is enabled in the preferences. The prototype runs on a 7 inch Samsung Galaxy Tab with Android 2.3.7.



(b) *DriveAssist*'s map view. The black car in the center represents the driver's vehicle. The large traffic sign in the bottom left corner indicates the type of a newly received traffic event. The small traffic signs indicate the position as well as the type of the traffic event on the map.



(c) *DriveAssist*'s warning screen. The warning screen shows the type of the detected traffic incident through well-known and simple traffic symbols. The direction of the event relative to the car is indicated by the red dot. The visual output is accompanied by a text-to-speech generated audio warning.



(d) When the traffic event is nearby (e.g. less than 15 meters away), the GPS accuracy may not allow indicating the precise position of the event. For that reason, the red border around the car shall symbolize the user that the event can be anywhere around the car.

Fig. 1: *DriveAssist*'s main menu as well as its active and passive traffic incidents visualizations.

when turning into this street. Additional information can be displayed by tapping on a warning icon. This information contains, among other things, the source of the information, a more precise description of the event, and, when available, also the length and the time-loss due to the event. For acoustic notifications about new nearby incidents, a circle of interest around the car can be defined. Newly detected events are also indicated by a larger version of the warning symbol in the lower left corner of the screen. Besides the map view, it is also possible to get a list view of all nearby incidents.

The warning screen is the passive warning module of *DriveAssist*. It is started and controlled by a service running in the background and can overlay any other application, such as a navigation application or the phone interface. Fig. 1c depicts the warning screen indicating a working area warning (WAW) which refers to a construction site 250 meters ahead. The warning sign describing the event type is complemented by a textual description ("Roadworks"). The car top view on the right hand side is used for visualizing the distance and the direction of the event relative to the car's long axis. The red dot indicates the direction of the incident by being displayed in one of the eight little squares around the car. Whenever the distance to the incident falls below a definable value that does not anymore allow a correct estimation of the direction, the dot is replaced by a red rectangle around the vehicle (cf. Fig. 1d). Together with a TTS output, this shall inform the driver that the incident is nearby and can be anywhere around the car. When there are multiple traffic events nearby, the controlling background service applies prioritization. Approaching, moving traffic events, such as moving emergency vehicles or a sharp braking vehicle, get higher priority than static events. Static events are prioritized by their distance to the vehicle.

Both warning modules offer TTS support. The speech cues allow informing the driver in a fast and reliable way even when the driver is distracted by a secondary or tertiary task [11], or has to focus on the primary driving task, as it could be the case for bad or highly congested driving conditions.

The information from V2X communication is currently derived from Cooperative Awareness Messages (CAMs) [12] and Decentralized Environmental Notification Messages (DENMs) [13]. So far, the following Day-1 use-cases [14] are supported by *DriveAssist*:

- Approaching Emergency Vehicle Warning (AEVW, CAM)
- Electronic Emergency Brake Lights (EEBL, DENM)
- Stationary Vehicle Warning / Post-Crash Warning (PCW, DENM)
- Traffic Jam Ahead Warning (TJAW, DENM)
- Working Area Warning (WAW, DENM)
- Hazardous Location Notification (HLN, DENM)

An obstacle of V2X communication is the penetration rate required for realizing an efficient warning system [15]. Early adopters have no real benefit when the penetration rate is still low. In order to provide functionality even at low V2X equipment rates, *DriveAssist* combines V2X data with data received via the PPD's mobile data connection. The Internet-based central traffic services (CTSs) are normally provided by service providers that collect and aggregate data from different sources. Common sources are the police, road maintainers, private persons, or automobile clubs.

4. USER STUDY

The application has been evaluated in a laboratory user test with 12 participants between 22 and 30 years (median age of 27 years) using the application for about 45 minutes. Most of them were students or research assistants. All participants were male.

The within-subjects study was performed for answering the following research questions (RQs):

- RQ1: Is the chosen user interface (UI) easy to understand and to learn?
- RQ2: Is text-to-speech (TTS) an appropriate way of supporting the visual warnings?
- RQ3: Would users prefer the map view, the warning screen, or a combination of both in order to get informed about a traffic incident?
- RQ4: What information is considered as useful and what information is still missing?

A simulation tool generated the data for the study. That includes the position of the subject's car, other traffic participants, and predefined traffic events. The Wizard of Oz technique [16] was used for triggering the defined events at the correct time. Four traffic scenarios with different levels of complexity were presented to the subjects. The most complex scenario is depicted in Fig. 2. The subject's simulated vehicle first approaches a traffic congestion. While the vehicle is passing by, a hazardous location warning is triggered. Directly after the hazardous location, a stationary vehicle warning is set off.

A questionnaire with open and closed questions was used for collecting the test data. Open questions invited the subjects to answer questions in their own words. The closed question set contained

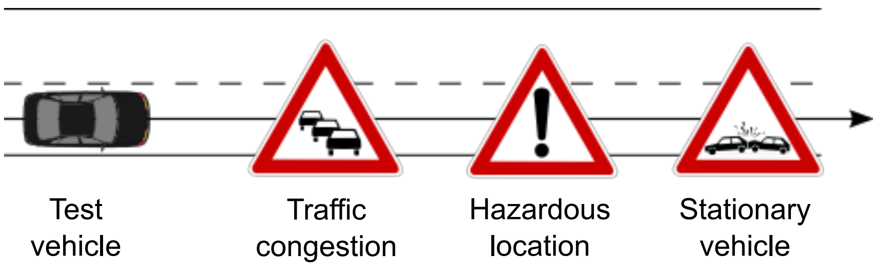


Fig. 2: A simplified diagram of the fourth scenario that was shown to the subjects. The test vehicle corresponds to the subjects' vehicle. The traffic incidents were arranged on a curvy road and spaced $150\ \mathrm{m}$ to $300\ \mathrm{m}$ apart.

yes/no-questions, questions with given answers and questions in which statements had to be rated on a Likert scale ranging from 1 (totally disagree) to 5 (totally agree).

First, the subjects had to read an introduction and to answer some introductory questions concerning their knowledge about similar systems. In the next part, *DriveAssist*'s main menu was presented to them. After having examined the main menu for some seconds, questions regarding their first impression had to be answered. In the following part, the four different traffic scenarios were used. While playing *Superball* (a freeware game that can be obtained from http://christoph.stoepel.net/ViewSoftware.aspx?id=0103), warning messages according to the scenarios were displayed by using the passive warning screen. Afterwards, the subjects were asked whether they had understood the situation. Those open questions were followed by general questions about the warning screen. For testing the map view, two scenarios were played by the user study supervisor and followed by the user. This time, the subjects fully concentrated on the map without playing the game. To collect their opinion about the map view, several statements had to be rated afterwards.

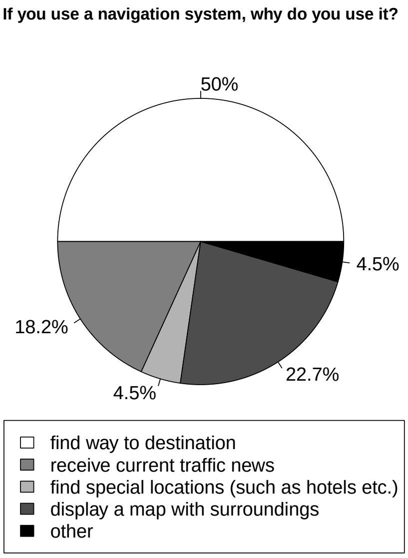
5. USER STUDY RESULTS

In order to be able to interpret the results, previous knowledge, expectations, and current usage of smartphones and navigation systems were recorded. From the 12 subjects, 10 subjects regularly use a smartphone and thus are familiar with the usage of mobile applications. 11 subjects use a navigation system on a regular basis. The main reason for using the navigation system is for finding a route to unknown destinations. However, the subjects also use the navigation system to display a map of the surrounding area and to be informed about the current nearby traffic situation (cf. Fig. 3a). In Fig. 3b, the traffic events causing the most trouble for the subjects are summarized. Except for the causes 'risky overtaking' and 'bad weather conditions', all other cases are supported by *DriveAssist*.

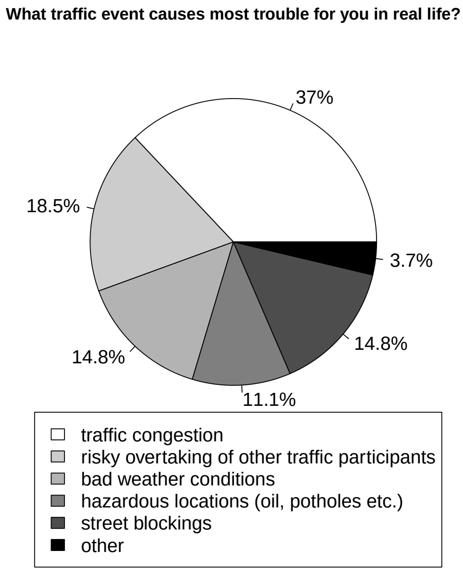
TABLE I: Number of nominations for a statement concerning the first impression on *DriveAssist*. The statements are rated from "I totally disagree" (TD), "I disagree" (D), "neutral" (N), "I agree" (A), to "I totally agree" (TA). Avg. stands for average value and SD for standard deviation.

#	Statement	TD (1)	D (2)	N (3)	A (4)	TA (5)	Avg.	SD
A1	The application seems to be complex.	3	7	1	1	0	2.00	0.85
A2	The application is graphically appealing to me.	0	3	2	7	0	3.33	0.88
A3	The menu seems to be well usable in a car.	0	2	1	3	6	4.08	1.16
A4	The menu reminds me of my navigation system.	1	7	4	0	0	2.25	0.62

The results for the evaluation of the main menu are summarized in Tab. I. **A1** and **A3** verify the clear and simple structure of *DriveAssist*. However, it is not as graphical appealing to the subjects



(a) The subjects use navigation systems mainly to find their way to (unknown) destinations. However, they also use them to display a map with surroundings and to receive current traffic news. ($n = 12$, multiple items could be ticked)



(b) For the subjects, traffic congestions cause most trouble in daily traffic. With the exception of risky overtaking and bad weather conditions, all chosen cases are supported by *DriveAssist*. ($n = 12$, multiple items could be ticked)

Fig. 3: Navigation system usage statistics and traffic trouble causes.

as it could be (**A2**). For eight subjects, the main reason why *DriveAssist* does not remind them of their navigation system (**A4**) was the 'lack of icons and graphics'.

TABLE II: Number of nominations for a statement concerning the warning screen.

#	Statement	TD (1)	D (2)	N (3)	A (4)	TA (5)	Avg.	SD
B1	I have quickly understood the presented warnings.	0	1	0	4	7	4.42	0.90
B2	The indication of the direction was useful.	1	2	5	3	1	3.08	1.08
B3	Sometimes the red dot was "bouncing". That irritated me.	6	2	1	1	2	2.25	1.60
B4	The warning screen interrupted my attention violently.	1	8	3	0	0	2.17	0.58
B5	The voice output is a useful way of supporting the warning.	0	0	0	3	9	4.75	0.45

Tab. II summarizes the results for the warning screen that pops up when a traffic incident is nearby. All but one subject could quickly understand the warnings (**B1**). The subjects explained that this was supported by the fact that standardized German traffic signs for indicating the traffic incidents' types have been used. Statements **B2** and **B3** refer to the red dot indicating the direction. For six subjects, the main point of criticism was the small size of the red dot, which made it poorly visible. Three subjects would prefer a continuous indication of the direction angle and one subject would omit the direction indication completely.

In Tab. III, the results concerning the map view are shown. In general, the subjects agreed that the map view is useful (**C2**), however all but three subjects explained that displayed incidents should be limited to the planned route (**C4**). Similar to the warning screen (**B1**), the used symbols were clear to the participants (**C3**). In comparison to the warning screen (**B4**), the map view needs more attention 'especially when multiple traffic incidents are displayed' (**C5**).

The voice output (**B5** and **C7**) got very good results. 10 subjects emphasized that it is a good extension to the visual display. One subject explained that he 'just shortly glanced at the warning

TABLE III: Number of nominations for a statement concerning the map view.

#	Statement	TD (1)	D (2)	N (3)	A (4)	TA (5)	Avg.	SD
C1	When a new warning is announced by the voice output, its position should be highlighted on the map.	0	0	3	3	6	4.25	0.87
C2	The overview provided by the map is useful.	0	3	0	6	3	3.75	1.14
C3	The meaning of the symbols is easy to understand.	0	1	1	6	4	4.08	0.90
C4	Only traffic events on my itinerary should be displayed.	0	3	0	3	6	4.00	1.28
C5	The map view requires a lot of attention.	2	1	5	4	0	2.91	1.08
C6	The map view reminds me of my navigation system.	0	1	0	3	8	4.50	0.90
C7	The voice output is a useful support for the map view.	0	0	1	3	8	4.58	0.67

screen to identify the direction [of the event].' For the map view, the subjects further demanded that the position and the type of a newly announced traffic event should also be mentioned via TTS and its position should be highlighted on the map (**C1**).

TABLE IV: Number of nominations for statements concerning on the overall impression of *DriveAssist*.

#	Statement	TD (1)	D (2)	N (3)	A (4)	TA (5)	Avg.	SD
D1	The navigation functionality is missing.	0	0	1	7	4	4.25	0.62
D2	I would only use the map view and omit the warning screen.	4	2	1	3	2	2.75	1.60
D3	Central traffic services provide useful additional information.	0	0	1	3	8	4.58	0.67

The results of statements on the overall impression of the *DriveAssist* system are given in Tab. IV. The combination of V2X data for real-time, nearby traffic information and data from Internet services for long-term, distant traffic events was seen as one of the major strength of *DriveAssist* (**D3**). The map view reminds the subjects of a navigation system (**C6**). For that reason, the subjects miss the navigation functionality (**D1**). This also corresponds to the ratings of statement **C4** that only traffic incidents on the current route should be displayed. Statement **D2** shows that the subjects had different preferences; for some, the map view would be sufficient. Three subjects mentioned that they would prefer to have both the warning screen and the map view at the same time with the warning screen displaying the warning with the highest priority.

6. DISCUSSION OF THE RESULTS AND RECOMMENDATIONS FOR V2X VISUALIZATION SYSTEMS

By providing answers to the formulated research questions, we give recommendations for the functional design and technical implementation of a V2X communication-based visualization solution.

RQ1 (Suitability of UI): In general, the user interface has been rated as good, except for the missing icons on the buttons of the main menu. For the warning screen, the direction indication is a weak spot. Two subjects suggested that a huge arrow continuously showing the direction to the event could replace the current indication. This idea came up due to the reason that the red dot sometimes quickly jumped between two directions. Contrary to this, other two subjects stated that the rough direction (front, left, right, back) indicated by a large bar or box next to the car's top view would be enough. Since the warning is normally displayed in cases when the driver should focus on the street, the simplified version should be preferred. In addition, the size of the font should be as large as possible since six participants complained about its readability.

In order that the map view can provide a good overview, only events on or nearby the planned route should be displayed. This requires the integration of navigation functionality into the warning system. When a relevant traffic event is received that would be outside of the currently visible map region, it should be displayed at the map's border for indicating its direction, or not displayed at all. When a new event is added to the map view, it should be announced via TTS and highlighted on the map in order to be distinguishable and recognizable as a new event.

The choice of warning symbols is also very important. In our application, we have used standardized German traffic signs. The subject that disagreed with statement **B1** was from outside the European Union and had never driven a vehicle in Germany. For that reason, he had difficulties with interpreting the shown symbols. The chosen symbols should be matched with the target country.

Another important point is the adaption of the screen to the brightness of the environment. When it is dark, the white background of the warning screen would be very exhausting for the driver even when the display is automatically dimmed. The same holds true for the map view. The bright colors should be replaced with darker ones in that case.

RQ2 (TTS support): The subjects rated the speech output as very important. Since the speech cues also contain the information shown on the screen, less attention has to be paid on the visual representation. Thus, it reduces the time drivers need to take their eyes away from the road. When the warning pops up first, the spoken message began with the word “attention”. Three subjects found this could be removed since it only delays the output of the crucial information. However, two of them wanted some kind of auditory icon at the beginning in order to direct their attention to the following speech output. The content of the spoken message should comprise the type of the traffic event, the distance, and the direction (only when warning is caused by a moving object).

For optimizing the audibility, the volume of the speech output has to be adjusted based on the environmental noise. For the TTS setup (e.g. gender or mode of expression), cultural differences should be taken into account to create a positive listening experience.

RQ3 (Mode of warning display): The subjects prefer a combination of the fast to understand warning screen for immediate incidents and the map view as an overview of surrounding incidents. When the display is large enough, both views could be combined side-by-side or the warning screen could partly overlay the map view as three subjects have demanded. A list with all received incidents was also tested. However, the subjects rated the list as useless as long as the events cannot be displayed on a map next to the entries.

One subject said that he would prefer the warning screen for severe and urgent warnings. Other warnings could be presented using the map view. That could, for example, be realized by using severity classes as it has been shown by Mitropoulos et al. [3]. Another subject suggested indicating the priority of an event by changing the background of the warning screen or by flashing the warning symbol. However, both measures would direct the driver's attention to the screen, which could negatively influence the driver's reaction time.

RQ4 (Useful and missing information): The user test showed that users expect such a warning system to be coupled with navigation functionality. The received traffic events should be included in the route calculation, e.g., for finding alternative routes. In addition, the route information should be used for avoiding the presentation of warnings that are irrelevant for the driver.

The subjects further pointed out that the available information and real-time communication channels should be used for improving the driving efficiency and comfort. For example, the vehicles could form a large network [17] that could optimize the overall and individual traffic efficiency by suggesting to change the mode of transportation, or to switch to routes with fewer traffic.

Other important aspects for the subjects were information security and privacy. They were afraid that wrong or forged V2X messages could be generated by attackers [18], which could lead to dangerous situations (e.g. warning of sharp braking vehicle in front). Since the position of their vehicles is also broadcasted, the participants were afraid that their driving could be tracked. Other concerns refer to the mobile application. It should be distributed via a trusted channel and updated regularly. For example, it could be installed and updated at garages or car dealerships. The available mobile application markets are seen as problematic, since anyone can upload imitations of regular applications and users are responsible for updating their installed applications themselves [19]. One subject mentioned that certificates from independent test institutions and guaranteed update mechanisms could create confidence.

7. CONCLUSIONS

We have presented the results of a laboratory user test performed with the V2X communication-based Android driver assistance system *DriveAssist*. By analyzing the results, we identified the key elements concerning the HMI of such as system. The user interface needs to be kept clear and simple in order to be usable while driving. The combination of a fast to understand warning screen for immediate incidents and a map view as an overview for surrounding incidents was preferred by most subjects. The results further show that the TTS output actively supports the visualization and is even sufficient for some subjects when it is not possible for them to look at the display.

The presented implementation of *DriveAssist* lacks navigation functionality. Currently, we are working on a second version with redesigned user interface and navigation support. The findings presented in this paper serve as guidelines for the new version.

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