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Evaluating Interactions with Non-existing Automated Vehicles: Three Wizard of Oz Approaches *

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Abstract— **Highly automated test vehicles are rare today, and (independent) researchers have often limited access to them. Also, developing fully functioning system prototypes is time and effort consuming. In this paper, we present three adaptions of the Wizard of Oz technique as a means of gathering data about interactions with highly automated vehicles in early development phases. Two of them address interactions between drivers and highly automated vehicles, while the third one is adapted to address interactions between pedestrians and highly automated vehicles. The focus is on the experimental methodology adaptations and our lessons learned.**

I. INTRODUCTION

Highly and fully automated vehicles (cf. NHTSA's automation level 3 and level 4 [1]) are currently under development, and several manufacturers have stated that they will be available on the market in the near future. However, the road towards such vehicles is not simple; there are many challenges to be addressed. One of the challenges is that we need to design functionality for vehicles that are currently not available for the general public [2]. At the same time, it is still an open research question how to evaluate the new functionality with respect to various human-factor issues, and what methods to use. The methods and criteria for evaluating driver assistance systems in manually operated vehicles have been under development for a long time, and they are rather well established today. However, it is not always possible to apply such methods and criteria to vehicles of higher levels of automation since the role of the driver is different, or there is no driver at all. In particular, human factors research at the higher levels of automation is lacking [3].

In this paper, we present and discuss three case studies using the Wizard of Oz (WOZ) technique to analyze interactions with automated vehicles from the perspective of drivers and pedestrians. The three case studies exemplify the use of WOZ techniques at different stages of the development process.

In the first case study (*A*), the WOZ is used to study interaction between pedestrians and highly and fully automated vehicles in a real-world traffic environment. In the second case study (*B*), the WOZ is used to evaluate medium-fidelity prototypes that simulate interaction between drivers and highly automated vehicles using an advanced driving simulator. In the third case study (*C*), the WOZ is used early in the development process to simulate the interaction between drivers and highly automated vehicles in a real-word traffic environment.

The focus is on the experimental methodology as such rather than the mere research findings from these case studies (the results from the first two studies are available in [4] and [5]). We discuss applicability of the WOZ in these use cases. In particular, we address questions related to experiment design, WOZ task, selection of participants and information provided to them.

II. WIZARD OF OZ TECHNIQUE

The Wizard of Oz (WOZ) technique is a well-established approach for evaluating user interfaces in various domains, from robotics [6] to mobile applications [7] and automotive industry [8]. It is based on the idea of simulating a fully working technical system by a human operator – a wizard [9]. It is often used to gather data from users who believe they are interacting with an automated system. However, in some cases the users are informed about the wizard and his/her role.

Compared with a real automated system, the WOZ setup generally enables less constrained experiments (through use of improvisation), and is often less expensive. Also, it may enable more systematically constrained experiments (by eliminating the limitations of an automated system) [10]. Previous studies have shown that the WOZ can be used both for testing systems, and as an iterative design methodology at various phases of the development process. When applied early in the development phases, it can be used to explore a wide range of possibilities and to identify key features of a system [6].

In the automotive domain, the WOZ technique has mainly been used to evaluate various interfaces (e.g., gesture-based, speech-based) for driver assistance, infotainment, and entertainment systems ([11], [12], [13]). Recently, it has been applied for evaluation of interactions with systems of higher level of automation, e.g., [8]. The WOZ technique has mostly been applied in driving simulators. This paper shows how it can be applied in real-traffic environment (*Case Study A* and *C*) and in a driving simulator (*Case Study B*).

III. CASE STUDY A: INTERACTION BETWEEN AUTOMATED VEHICLES AND PEDESTRIANS IN REAL TRAFFIC

In *Case Study A,* a field experiment was carried out to compare how pedestrians experience encounters with a manual versus automated vehicle in a realistic traffic environment [4]. Here, a driver actively seeking eye contact with pedestrians represented a manual vehicle. An

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automated vehicle was, on the other hand, characterized by driver behaviors that are rare today but may become common in future (talking on the phone, reading news paper), as well as an empty driver seat (symbolizing a fully automated vehicle). The first mentioned refers to NHTSA's level 3, while the latter refers to level 4 [1]. A WOZ approach was used to emulate encounters with an (seemingly) automated vehicle.

A. WOZ setup

To create the WOZ setup, a dummy steering wheel was installed in a right-hand steered vehicle (a Volvo V40) and the real steering wheel was hidden from pedestrians' sight. This way, it appeared to be a standard left-hand steered vehicle seen from the perspective of pedestrians (Fig. 1). The fake driver on the left-hand side interacted with the pedestrians and seemingly drove the vehicle or was engaged in other activities (phone, newspaper). There was also a condition with no driver at all (but the real driver in the right-hand seat was still visible). The experiment was carried out at the Chalmers University of Technology on a dead-end street (see Fig. 1).

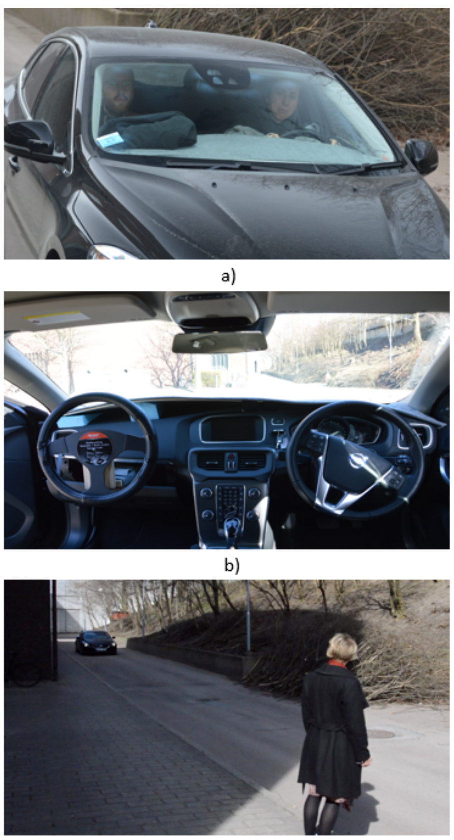

Figure 1. Exterior (a) and interior (b) of the test vehicle, and the test environment (c).

B. Experimental/evaluation approach

The test was set up as a "would cross/would not cross" experiment. The focus was on pedestrians' (un)willingness to cross the street as an indicator of the perceived safety. Also, the reasoning behind their (un)willingness was explored as well as their emotional experience.

C. Procedure

The test leader informed the pedestrian that he/she would interact with a vehicle, without mentioning that the vehicle could be automated. The pedestrian then filled in a background form, and took a given position at the curb near an "imaginary" zebra crossing (ca 0.5 m from the roadway). To get familiar with the experiment, the pedestrian always experienced an introductory encounter where the (fake) driver tried to make eye contact with him/her. Next, the experiment was executed in three blocks where each pedestrian experienced eight encounters in total.

In *Block A*, the pedestrian was standing at the same position as in the introductory encounter, facing the test vehicle that approached at a speed of 7 km/h without slowing down. The (fake) driver was seeking eye contact with the pedestrian, talking on the phone, or reading newspaper, which resulted in three encounters experienced in a random order. The pedestrian's task was to observe the vehicle and indicate when it would feel uncomfortable to cross by turning towards the test leader. In *Block B*, the pedestrian was facing the test leader while the vehicle was approaching at a speed of 7 km/h. When the vehicle stopped (ca 2 m from the zebra crossing), the test leader signalized to the pedestrian to turn around and answer the following question: *Would you cross the street now?* Meanwhile, the (fake) driver was seeking eye contact with the pedestrian, talking on the phone, or reading newspaper. This resulted in three encounters that were experienced in a random order. In *Block C*, each pedestrian experienced two encounters at a random order: one with vehicle in motion and one with standstill vehicle. The pedestrian tasks were same as in the previous two blocks. However, the (fake) driver was not present in the driver seat (simulating a completely autonomous vehicle). The first two blocks were executed in a random order, while *Block C* was always presented last to avoid excessive order effects. After each encounter the pedestrian completed a Self-Assessment Manikin (SAM) questionnaire [14].

After finishing all encounters, the pedestrian participated in a semi-structured interview. The total time of the experiment was approximately 30 min, depending on the length of the interview.

D. Participants

To participate in the study, the pedestrians had to be familiar with the test location and frequently travelling by foot. In total, 13 pedestrians were recruited (7 male, 6 female) through direct contact at Chalmers University of Technology.

E. Data collection and analysis

The data collected consisted of the Self-Assessment manikin (SAM) [14] questionnaire documented on paper, statements of (un)willingness to cross, and a semi-structured interview that was audio recorded. SAM is a nonverbal assessment method that measures the valence, activity, and control associated with a person's affective reaction to stimuli. To identify the pedestrians' emotional state, the valence and the activity scores were combined using the Circumplex model of Affect [15]. The interviews were transcribed, and then imported into ATLAS.ti® qualitative research software where a qualitative assessment was performed using data reduction and open coding [16].

F. *Summary of results*

The results show that pedestrians' willingness to cross the street decrease with an inattentive driver. Eye contact with the driver on the other hand leads to calm interaction between vehicle and pedestrian. In conclusion, to sustain perceived safety when eye contact is discarded due to vehicle automation, the vehicle needs to communicate its intent using an external interface and/or the vehicle's own motion pattern.

IV. Case Study B: Interaction between Automated Vehicles and Drivers in Driving simulator

The focus of *Case Study B* was to explore whether or not drivers feel the need to control tactical decisions when operating highly automated vehicles, (level 3 [1]) and in that case, which tactical decisions are important to control, and under which conditions they are needed [5]. The purpose of tactical commands is to give the driver increased feeling of control by letting the driver make decisions that the vehicle then performs. For example, if the driver prefers to overtake a vehicle while in automated mode, an "overtake" command lets the vehicle decide when it is safe to overtake instead of switching to manual maneuvering. The topic was addressed by conducting an experiment in a driving simulator by means of a WOZ approach described here. The drivers gave the following tactical commands by using a controller interface: a) change lane to the left/right, b) overtake, c) take the next exit, d) park, and d) turn left/right.

A. *Tactical controllers*

Three master thesis project teams were assigned the task of developing high-level prototypes for tactical control of highly automated vehicles that resulted in *Controller I-III.*

Controller I is based on a tablet-PC application and was mounted in a stationary position in front of the center stack. The tactical commands are given through touch gestures on the touchscreen, supported by visual cues (Fig. 2).

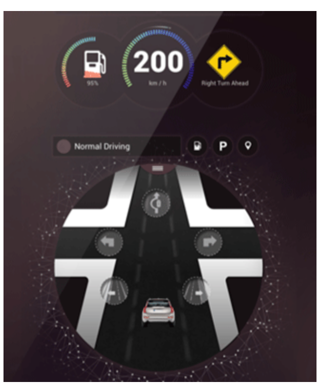

Figure 2. *Controller I* where tactical commands are given by drag-and-drop interaction on the tablet's touchscreen. The feedback to the driver is visual.

Controller II uses gestural input on a touch surface. The prototype was built using the same hardware as *Controller I* and was placed horizontally on the center console between the seats. To give commands, the driver swipes the pre-defined single-finger gestures on the input surface (Fig. 3, left). Once the command is given, a corresponding icon is displayed in the instrument cluster (Fig. 3, right), and a sound is played, providing feedback to the driver.

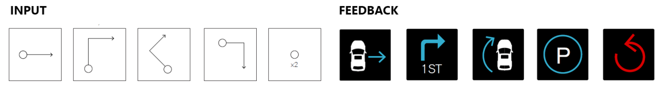

Figure 3. Finger gestures (left) and visual feedback in the instrument cluster (right) in *Controller II.*

Controller III uses the gear stick (joystick) to issue commands. Input is given by moving the stick using different gesture patterns (Fig. 4). After being issued, the command is validated by the vehicle, and either accepted or rejected. If a command is accepted, the gearstick provides haptic and auditory feedback, and stays in the given position until the command is executed. If a command is rejected, haptic and auditory feedback is provided while the stick moves back to the original position in the center. In all controllers, a given command can be aborted, unless the execution has started.

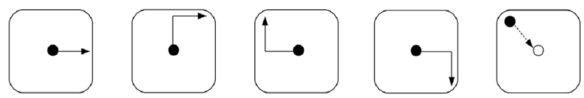

Figure 4. The patterns for giving different commands using *Controller III.*

B. *WOZ setup*

To create a highly automated vehicle experience in the fixed base driving simulator, a WOZ approach was used (Fig. 5). That is, a human WOZ-driver, who used an additional steering wheel and pedals to control the vehicle, provided the automated functionality. The feedback to the controllers was also managed using a WOZ approach. When the test driver's tactical command was registered, an assistant provided appropriate feedback in a timely manner. The test drivers' tasks were pre-defined and displayed as text on the simulator screen. Thus, repeatability between tests was achieved, at the same time as the wizards knew the next step beforehand. Silent communication between the wizard driver and the assistant, who could see and control the interface feedback from behind, ensured a timely execution of commands given by the participant. The wizard and assistant took their places silently while the test participants were given an introduction and learned the interfaces and simulator. The traffic environment incorporated a typical Swedish highway (ca 6 km) and a rural road (ca 3 km), as well as two small cities (ca 3 km). Depending on the environment, the speed limits varied between 50 km/h (city), 70 km/h (rural road) and 90 km/h (highway).

C. *Experimental/evaluation approach*

The test was set up as an experiment in which each driver experienced two of three controllers. That is, drivers could compare their experiences using different controllers. The major premise was that drivers who are allowed to affect tactical decisions of their highly automated vehicles would experience a high level of satisfaction and feeling of control.

Figure 5. The driving simulator and the WOZ driver acting as the vehicle automation in *Case Study A*. The WOZ assistant providing interface feedback was seated to the right of the wizard driver (empty chair).

D. Procedure

Each participant evaluated two of the three controllers (*Controller I-III*). The pairwise experimental setup was a compromise to extend the length of each test, yet avoid a prolonged test procedure for each participant. The experiment procedure was divided into seven steps depicted in Fig. 6.

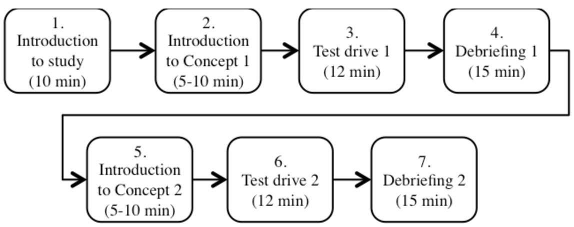

Figure 6. Procedure in *Case Study B*.

- Steps 2 & 5: Introduction to the controllers. After the initial test drive, the drivers learned how to use the tactical controller to be tested.
- Steps 3 & 6: Test drives. Both test drive 1 and 2 were carried out on the same road (ca 12 km), and each of them took approximately 12 minutes to complete. To achieve a comparable evaluation of the controllers, the test drivers were prompted by a text message to give a specific command to the vehicle.
- Steps 4 & 7: Debriefing and evaluation. After each test drive, the participants completed two questionnaires and a set of interview questions. The interview was semi-structured and a video recording of the test drive was also used to make it easier to discuss different events in the drive.

E. Participants

In total, 17 drivers (9 male, 8 female) participated in the experiment. They were recruited via e-mail contacts. The criteria for participating in the study were that they were holding a driver's license, and that they were not directly involved in research and development of automated vehicles.

F. Data collection and Analysis

The data collection consisted of questionnaires and interviews. To assess the test drivers' experiences after each test drive, they were asked to complete two questionnaires and to participate in an interview. The first one was based on the User Experience Questionnaire (UEQ) [17], which probed the drivers' user experience. The other one was based on a somewhat modified Technology Acceptance Model (TAM) [18]. The TAM questionnaire consisted of 11 statements where the drivers rated their assent/dissent using a Likert-scale. The semi-structured interview probed the drivers' experience of travelling in an automated vehicle, how they experienced issuing the tactical commands, and if the concepts fulfilled their expectations.

G. Summary of results

The results indicate that the drivers experienced a need to affect tactical decisions of highly automated vehicles. Several of the tactical commands were found useful, especially in a rural road and highway context. It also gave them a feeling of being in control of the vehicle, suggesting that command-based driving might be a way to keep drivers in the control loop.

V. Case Study C: Interaction between Automated Vehicles and Drivers in real traffic

The focus of *Case Study C* was to explore the effect of being able to control tactical decision when operating highly automated vehicles (level 3 [1]). This is similar to *Case Study B*, however, here, the evaluation was carried out using a touch screen controller and in real-world traffic.

A. Tactical controller

The controller was developed in a student project and is based on a tablet-PC application (Fig. 7) where tactical commands are given through touch gestures on the tablet's touchscreen, supported by visual cues (similar to *Controller I* in *Case Study B*). The controller provides visual (graphical and textual) feedback to the user.

Figure 7. Illustration of the final controller design in *Case Study C* that enables drivers to issue tactical commands to highly automated vehicles.

B. WOZ setup

The test participant was seated in the back seat with an occluded view of the front seats where the wizard driver and a wizard assistant were seated (Fig. 8). A camera was mounted in the front windshield and connected to a display in the back seat to give the test participant a view of the traffic in front. The test participants were given a tablet with the interface that enabled them to give tactical commands to the automated vehicle. When the test participant gives a command, it is displayed to the wizard assistant on a secondary tablet. The assistant then accepts/rejects the given command and sends feedback to the test participant's tablet, and gesticulates the action required to the wizard driver who in turn performs the action.

C. *Experimental/evaluation approach*

Two WOZ tests were conducted. The focus was on capturing drivers' experience of tactical commands given that they are the "drivers" of a vehicle that is currently operated in the automated mode. One test was set up as an exploratory field experiment in real traffic in which the participant conducted a test-ride between two pre-defined destinations (involving both sub-urban road and highway). The second test was conducted in a more controlled environment (parking lot) enabling a better repeatability. A participant could not take part in both tests.

D. *Procedure*

A similar procedure was used for each of the performed WOZ tests. Before starting the experiment, a test leader asked the test participants to sit in the back seat of the test vehicle to complete a short questionnaire focusing on their background (e.g., age, driving experience). After, they were briefed about the experiment and their task. Basically, they were informed about characteristics of highly automated vehicles and that they would operate such a vehicle. They were also informed that they would be, for the sake of the experiment, seated in the back seat instead of the driver seat. A curtain occluded the participants' frontal view, but the participants were allowed to view the traffic in front of the vehicle via a display. Additionally, the test participants were provided with a contextual scenario: *Imagine that you are on the way home from your work. As usually, you enter your vehicle and you seat yourself in the driver seat. As your vehicle is automated, you don't need to maneuver it; you just need to set "home" as your destination via a tablet application. The vehicle will be then driving on a predefined route unless you give one of the commands available via the tablet.* They were also informed that the "home" was in fact predefined and not their real home. The participants were asked to think aloud while interacting with the tablet. A test leader was always present next to the participant to guide the participants and answer questions that they may have.

E. *Participants*

Each experiment involved 5 participants, resulting in a total of 10 participants. The participants were mainly students and employees at the Halmstad University, or at the nearby companies. The criterion for participating in the study was that they were holding a driver's license.

F. *Data collection and analysis*

The data were collected via a pre and a post questionnaire. The pre questionnaire capturing the demographics and background of the participants was completed prior to the experiment, while the post questionnaire was sent to the participants after the test, giving them some time to reflect over their experiences. In addition, a camera was installed in the vehicle to capture direct feedback from the participants.

G. *Summary of results*

The results show that a quick response and feedback from the system when a tactical command is given amplifies the feeling of being in control. The participants appreciated clear motivation when a command was rejected. They suggested that several commands would be possible to issue, and that it should be presented which of them is to be executed next. The feedback from the experiments led to a re-design of the controller, however, it has not been evaluated yet.

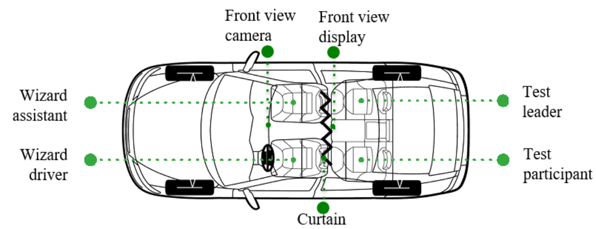

Figure 8. The WOZ set up in *Case Study C* with a curtain occluding test participant's view and the camera providing the view of the traffic in front of the vehicle. The test participant is seated in the back seat.

VI. Discussion

A. *Is WOZ a suitable method to evaluate automated vehicle?*

In *Case Study A*, 13 pedestrians encountered two different vehicle behaviors and several different driver behaviors, including a situation with no (fake) driver (i.e. a situation simulating a fully automated vehicle). The Wizard of Oz (WOZ) approach was successful in the sense that all pedestrians believed that they were encountering an automated vehicle. To start with, when encountering the vehicle where the fake driver was engaged in activities that are not common today, a great majority of them felt unsafe and experienced discomfort, i.e. they did not suspect that the vehicle was automated or driven by a wizard. When they finally encountered the vehicle with the empty driver seat, some of them could not grasp that the vehicle was in automated mode. From that point of view, pedestrians should have been informed that they would face an automated vehicle. The test participants in *Case Study B* were informed that they would interact with an automated vehicle, however, none of them suspected that the vehicle was driven by a wizard; in that respect the WOZ as applied in *Case Study B* was also successful. For *Case Study C*, the WOZ was successful in the sense that it provided a context of use for the participants, as well as for the developers, early in the development process.

B. *What information to provide to the participants?*

Ethical concerns about WOZ and its inherent social deception are raised by several researchers in various domains (see e.g., [19]). While some of them discuss the embarrassment test participants feel after they learn they were deceived, others discuss ethical problems faced by the test leaders when balancing what to tell the participants and problems where the participants cannot determine what/whom they are interacting with (referred to as "Turing deceptions" [20]) . In our case studies, we have not seen any indications of test participants feeling offended by having been exposed to the WOZ approach. One approach we have used is to inform all test participants (e.g., via e-mail) after the experiment has been finished. This avoids the risk of revealing the method in advance, at the same time as the participants will not experience they have been deceived face-to-face.

C. *Which data should be collected?*

Several types of data can be collected using the WOZ methodology. In our case studies, the data collected included behavioral change, user experience (e.g., subjective ratings), and emotional response. However, there are issues to be considered. A general assumption in our WOZ data-gathering approaches was that user behavior would not vary substantially between the WOZ and automated experimental setups. The question is if the driving behavior will remain the same when automation maneuvers vehicles and how that may affect the value of WOZ experiments? Since human drivers have an inherent variability in their performance (which might differ from the automation's) the validity of using human wizards to study interaction in experimental setting should be further studied. We believe that it is a useful method, but how the conclusions are drawn from such studies and how it is used, especially later in the design process, should be carefully considered. Also, the WOZ allows for interaction in realistic traffic situations, but achieving repeatability in such dynamic settings is challenging. It is likely that the test participant and wizard adapt to each other to some extent. Then the question is how does it affect the conclusions we draw from studies, and is it possible to account for such effects?

Another finding is that the test participants' expectations of vehicle automation might differ, which probably affects subjective ratings if such measures are used. Therefore, the expectations should be surveyed before an experiment is started to be able to compensate for this in the analysis.

VII. Conclusions

To conclude, we have presented three alternative adaptations of the Wizard of Oz (WOZ) methodology for evaluation of interactions with automated vehicles. The adapted methods were successful in that the participants did not suspect that a wizard was involved. Also, they proved to be powerful tools for gathering information early in the development process. Gathering information about participant's perception about and expectations of automated vehicles prior to the experiment could be a way to support understanding of subjective measures. Furthermore, our WOZ methods allowed for interaction in realistic traffic situations, but achieving repeatability in such dynamic settings is challenging. On a final note, the true validity of the WOZ methods is difficult to prove since a comparison with real systems is not possible as yet.

Acknowledgment

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