Asia – Design Engineering Workshop (A-DEWS) 2017
December 11-12, 2017, Seoul National University, Seoul, Korea

How can communication between Autonomous Vehicles & Humans be improved by using Virtual Reality?

A safe, cost- and time-efficient method for the validation of Human Machine Interaction concepts in the context of public transportation in Singapore.

Sebastian Stadler*#, Dr. Henriette Cornet*, Penny Kong* and Prof. Fritz Frenkler*

* Design for Autonomous Mobility, TUMCREATE Ltd, Singapore
# Corresponding author's E-mail address: sebastian.stadler@tum-create.edu.sg

Abstract

Beyond the private transport sector, public transportation is also developing in the direction of full automation. Thus, new challenges arise for passengers inside the autonomous vehicles as well as for pedestrians and other traffic participants. In particular, the future interaction between human and autonomous vehicles (AVs) is still an open and unsolved field. How will pedestrians communicate with an approaching AV at a zebra crossing? How can information and interaction inside an AV prevent anxiety amongst passengers? Building up experimental setups in real-life conditions to answer these questions would be a complex endeavour: It would be costly in terms of both money and time, and could be unsafe for potential test persons. Therefore, with the help of Virtual Reality (VR), an alternative research method is proposed in this paper to answer the aforementioned questions in a reliable way that keeps costs and time spent to a minimum while maximizing safety for test persons. With the help of Head Mounted Displays (HMDs), test persons can be immersed in a virtual environment where experiments can be conducted. Besides the validation of Human Machine Interaction (HMI) concepts for pedestrians and passengers, the results are expected to prove the VR method to be a safe, cost- and time-saving alternative to conventional experiments in real-life conditions. Opportunities for further investigations consider the transferability of the concepts to other fields, necessity for standardization and regulation as well as exploration of user perception of AVs within public transportation for better acceptance.

Keywords: Human Machine Interaction, Computer-Aided Design, Virtual Reality, Human Factors, Design Methods and Tools, Autonomous Vehicles, Public Transportation, User-centred Design

1. Introduction

Transportation is developing in the direction of full automation (Level 5 automation). In contrast to level 0 automation, which means the human driver has to perform all aspects of the driving task, level 5 automation means that humans do not overtake or influence any task in any driving situation, but act solely as passengers (SAE, 2014). Mentioned technology is estimated to be implemented into daily traffic by 2030 (IHS, 2014). A study on autonomous vehicles (AVs) by Intel & Strategy Analytics (2017) predicts an economic opportunity of $800 billion annual revenue in 2035, following an exponential trajectory to hit $7 trillion annual revenue by 2050. This growth will be generated by businesses working with level 5 AV technology. Furthermore, the study predicts that 585,000 lives could be saved between 2035 and 2045 due to this technology (Intel & Strategy Analytics, 2017). However, the advances of full automation technology are not solely advantageous, but bring with them challenges, especially regarding user behaviour, acceptance and safety. At TUMCREATE, where research is focused on AVs in the context of public transportation for Singapore in 2030, industrial designers are tackling these challenges with a user-centred design approach. Questions within this topic include:

1. How could future vehicle to pedestrian communication be designed in an effective way to ensure safety without restricting traffic flow?
2. What information has to be provided for passengers using an autonomous public transportation in order to prevent anxiety and therefore support user acceptance?

With the help of Human Machine Interactions (HMI), these uncertainties are addressed regarding visibility, comprehensibility and thus, safety. Nevertheless, challenges arise regarding the data collection and validation for aforementioned designed HMI concepts. The degree of complexity, effort and safety are essential considerations for data collection in the context of AVs. Therefore, Virtual Reality (VR) is used as a method for validation. Regarding this VR method, questions to be answered are:

1. How can VR support the design of HMI concepts for AVs in public transportation?
2. What are the advantages of using VR as a data collection method?
3. What can be done to ensure that data collected within VR is reliable?

This will lead to the overall research question: *"How can communication concepts between Autonomous Vehicles & Humans be designed using Virtual Reality?"*

2. Related Work and Research Gap

Literature research was conducted regarding HMI for AVs, especially for the scenarios that are conducted within the case study (section 4):

1. AV2PED: Vehicle-to-pedestrian communication
2. AV2PAS: Vehicle-to-passenger communication

Further literature review dealt with the usage of VR, especially in the product development process and in industrial use.

The first experiment deals with vehicle to pedestrian communication (AV2PED). This covers the interaction between the human and approaching AV, when the human is standing in front of a road without traffic lights and with a potential intention to cross. This also includes zebra crossings. In this scenario, communication will change with the implementation of full automation technology for vehicles. Currently, pedestrians communicate directly with the driver of an approaching car. This happens preferably via eye contact (Šucha, 2014). Schneeman (2016) states that in future, there must be alternative communication techniques that are capable of substituting the driver's gaze.

Car manufacturers have already published potential HMI solutions within level 4 and level 5 AV concept cars dealing with the AV2PED scenario:

- Mercedes, for instance, proposed an HMI system inside their Mercedes F 015 concept car in 2015: With the help of laser projections on the pavement, pedestrians are visually informed about the AV's intention. This is combined with visualizations on a screen located underneath the windshield of the car. Furthermore, an audio signal is included in the concept. The laser not only indicates pedestrian detection but also creates a projected zebra crossing on the pavement. This visually makes clear to the pedestrian that it is safe to cross the road. However, there is no published validation of the concept regarding visibility and comprehensibility, especially regarding the laser technology (Mercedes, 2015). Due to the possibility of various weather and light conditions, this concept remains unproven regarding safety.

- With the Nissan IDS concept, a solution was proposed dealing with the same scenario but with a screen inside the windshield supported by an LED stripe at the side of the vehicle (Nissan, 2015). But, similarly to the F 015 from Mercedes, Nissan does not have a published validation of concept, especially regarding visibility and comprehensibility in various weather and light conditions.

- BMW published an HMI concept with the Vision Next 100 concept car. A crystal-shaped light indicator behind the windshield, called "Companion", signals via colour and light whether it is safe for pedestrians to cross the road or not. Furthermore, it states if the car is driving in manual or autonomous mode since the Vision Next 100 is a level 4 AV. As is the case with the two aforementioned concepts, no validation has been published for this concept yet. (BMW, 2016)

Regarding the topic of HMI for AVs, Clamann (2016) tested HMI concepts using a screen attached to the front of an AV as a potential communication channel. Still, the vehicle was manually driven by a human. This was also visible for the test persons. There were no significant differenc es between the test results with and without using the HMI on the screen. Therefore, Clamann derived that there is no significant help from displays and that people likely rely more on signals like gap distance to the approaching vehicle.

The second scenario deals with the In-Vehicle Information for Passengers inside autonomous public transportation (AV2PAS). Schoettle (2014) found that 45.9% of survey respondents are very concerned about autonomous public transportation. In another survey, Dong (2017) discovered that only 13% of respondents would be willing to ride a bus without any employee on board. Furthermore, Giffi (2017) states that people do not trust AVs to make critical decisions or judgements yet.

One reason why there are few publications available within the scope of the two aforementioned scenarios is the absence of proper methods for data collection. Recreating traffic conditions with level 5 AVs would require significant time and monetary investment. This is owing to the complexities of the scenario and technology. More importantly, the experiments would still remain dangerous for potential test persons, since AVs could misinterpret certain situations. One example that underlines this safety issue is a fatal accident caused by the wrong interpretation of the situation by a Tesla Model S in self-driving mode (circumstances of the accident described by The New York Times, 2016).

VR is already implemented in the product development process in various fields like the aerospace, automotive, construction and military industries. Car manufacturers, for instance, use VR to test and validate visibility, ergonomics and reachability. VR can validate concepts especially when there is no physical prototype available (Berg & Vance, 2016). Mihelj (2014) states that the use of VR is more effective in certain situations, such as pilot training in a simulator compared to real-life training. Furthermore, errors (technical and human) could lead to injury or equipment damage. Another advantage of VR experiments is the ease of conducting tests with the possibility to change conditions like weather and design features before building a physical prototype (Mihelj, 2014). This means that VR offers the possibility of validating concepts in a faster way than physical prototyping.

Based on these insights, the objectives of the research presented is to use VR for designing and validating HMI concepts for level 5 AVs, in order to solve the complexity, resource and safety issues related to building experiments in real-life traffic conditions.

Figure 1 states the potential issues that arise in both scenarios of the study with the implementation of level 5 automation. The last column gives the benefits of using experimental setups within VR instead of physical prototyping and real-life experiments.

	Potential issues connected to level 5 AV technology that needs to be addressed with HMI	**Role of HMI for AVs/design**	**Problems connected to tests within real-life conditions**	**Benefits of using VR instead of physical prototyping**
AV2PED	- No eye contact with driver - AV's driving intention not obvious for pedestrian ➔Feeling of anxiety increases ➔Increased risk of accidents pedestrians	Outside the vehicle: - Indication of pedestrian detection - AV's driving intention to pedestrians (e.g. AV is decelerating)	- Need for a level 5 AVprototype - Authentic traffic condition has to be re-created ➔Experiments are potentially dangerous for the test persons ➔Cost- and time-intensive	- Safety for the test persons - Cost- and time-effective - Different concepts can be tested
AV2PAS	- AV's driving intention and detection system not visiblefor passengers ➔Feeling of anxiety increases	Inside the vehicle: - Indication of general information related to AV technology like intention (e.g. AV is decelerating) - Indication of detection (e.g. AV has detected a pedestrian or other road user)		

Fig. 1: Potential issues of AV experiments and the benefits of using VR

The hypotheses to be validated are:

- With the help of VR, justifiable and reliable data can be collected in the context of AVs
- VR is a safe, cost- and time-efficient alternative to physical prototyping in the aforementioned scope

3. Method: VR set-up for experiments with test persons

The method developed requires test persons, material setup and defined experiments.

Test persons for the experiments are representatives of the study population, recruited according to demographic characteristics such as ethnicity, age and gender. Quota sampling is used as a method to obtain a representative number of participants. A token of appreciation in the form of a cash incentive is distributed to test persons to thank them for their participation.

With the help of a Head Mounted Display (HMD) a test person is fully immersed in a virtual environment. This is supported by headphones. Depending on the experiment, input devices, such as gamepads, are used.

The test area is an empty space of approximately 4.5 m x 4.5 m, allowing the test person to move freely during the experiment. Position tracking is included inside the test area. This means that the test person's movements are tracked in addition to the position of the head, which enables the observation and investigation of movements in the virtual environment. A backpack PC is used as hardware for powering the HMD so that the test person can move inside the test area without the risk of stumbling over cables. Additional hardware is located outside the tracked area. A screen or a projection on a wall allows observers to see the test person's view. Both, the test person's movements and first person view are recorded for later analysis. Figure 2 shows a possible setup for the experiments within VR.

Fig. 2: Possible set-up for experiment within VR (source: TUMCREATE)

One test person is tested at a time. To start, the test person undergoes a tutorial to be familiarized with the VR technology and the environment. This tutorial contains visual examples of the imminent experiments. Beyond that, within the tutorial, the test person is requested to move and interact within the virtual environment. To minimise the chances of VR-sickness[1] occurring, the tutorial and experiments do not exceed a combined procedure time of 6 minutes. The tutorial is followed by one of the aforementioned experiments. Both experiments are conducted independently.

---

[1] VR-sickness = Due to the VR technology, symptoms similar to motion sickness (e.g. headache, nausea, vomiting, etc.) may occur.

Then, experiments are conducted with the help of videos, pre-rendered animations and/or simulations. Within the experiments, the test person is instructed to complete one or more specific tasks (e.g. crossing the road or identifying semantics as quickly as possible). Data collection methods – observation of the test person, time measurements, error analysis and interviews before, during and after the experiment – allow a deeper comparison of concepts.

To validate the VR methodology as a reliable data collection tool, a benchmark experiment needs to be conducted. A scenario (e.g. waiting for a bus) is selected to function as a point of reference. The experimental setting is created in VR and in real-life conditions. After conducting the experiments, collected data from both settings are compared for the congruence of outcomes. This determines the limitations and boundaries of the VR method.

4. Case study for Singapore's public transportation

The case study, demonstrated in this paper, is conducted for the design of HMI for AVs in the context of public transportation in Singapore. Therefore, the test persons are people who live in Singapore and recruitment has to reflect the multicultural distribution of Singapore between Chinese, Malays, Indians and others. Additionally, a wide array of age groups has to be represented (children, adults, seniors) and the gender distribution has to be equal.

In the AV2PED experiment the test person is immersed into the situation where he/she stands at a sidewalk in front of a road. The specific task for the test person to complete is to cross this road. During this situation an AV approaches the test person. Then, the test person has to assess the situation and act accordingly. This means that he/she has to decide whether it is safe to cross the road or not. The approaching AV is equipped with various active HMI concepts differing in level of innovation and technology as well as displayed content. Passive HMI will also be included in the experiment. Thus, a cluster of concepts can be created, tested and compared afterwards.

These concepts follow basic design requirements like ergonomic aspects of positioning, visibility and readability. Active and passive HMI can be separated based on their main purposes. The goal of an active HMI is communication and, therefore, providing information. An example of an active HMI in this context is a screen which is attached to a vehicle that displays the AV's intention. Passive HMI means that information can be perceived from the AV from displays of other functions, such as the AV's deceleration. While the main purpose of the deceleration is for the AV to slow down or stop, the deceleration additionally indicates to the pedestrian that it is safe to cross the road at a certain point. Before starting with the actual scenarios, the aforementioned tutorial is conducted to make the test persons feel comfortable within the virtual environment.

To measure the visibility and comprehensibility of the HMI concepts, the reaction time required by the test person to detect the AV's intention is measured. One way to achieve this is by using an input device like a gamepad. Here, the test person has to push a button as soon as he/she can assess the situation. Another way is to measure the time elapsed before the test person starts crossing the road (i.e. starts moving inside the test area). With the help of an error analysis[2], the comprehensibility of the concepts' semantics can be validated. Subsequent interviews give insight into the test persons' feelings (like perceived safety, anxiety, etc.). Finally, through the analysis and comparison of collected data, the most effective HMI concept regarding visibility and comprehensibility can be derived.

---

[2] Error analysis = How many and what kind of errors did the test person make during the experiment and why did the mistake happen

In the first AV2PED scenario, only passive HMI is tested. This means that no active communication channel is used within the experiment. The scenario consists of approaching AVs with various braking distances and deceleration speeds. A randomized sequence is used to make sure the order of testing does not distort the outcome of collected data (see Table 1).

In the second AV2PED scenario, the commonly-experienced scenario at a junction with traffic lights is recreated with help of active HMI. Via a screen underneath the windshield, the AV shows traffic lights with red and green colour coding. These lights indicate if it is safe to cross or not. Additionally, this is supported by an audio countdown commonly used with traffic lights in Singapore (the sound indicates the start and end of the crossing phase). Furthermore, a visual countdown on the screen indicates when the AV will resume driving (presumably if there are no further pedestrians crossing the street) (see Table 1).

Within the third AV2PED scenario, a high degree of technology is used. This means that a laser projection on the pavement is used to communicate with pedestrians, supported by an LED stripe on the vehicle. Like in the previous scenario, the visual communication is supported by an audio signal to follow the rules of redundancy of channels in ergonomics. While the laser projection indicates the detection of pedestrian(s), the LED stripe displays the AV's intention. The LED stripe displays when it is safe to cross the road. The sound consists of a repeating short tone that increases in tempo until it turns into a constant tone. This indicates that the AV will resume driving (see Table 1).

To ensure that the order of scenarios does not distort the results, the second and third scenarios have a randomized sequence. However, the scenario with the passive HMI (Scenario 1) is always conducted first. The reason is that people are expected to be biased after the active HMI scenarios, and therefore act differently when dealing with the passive HMI (see Table 1).

Table 1: Overview of AV2PED Experiment

Scenario	0	1	2	3
Concept	Tutorial (e.g. finding a bus stop)	Passive HMI: (e.g. braking distance and deceleration)	Active HMI: Indication of driving intention (e.g. AV is decelerating) and pedestrian detection via screen and sound	Active HMI: Indication of driving intention (e.g. AV is decelerating) and pedestrian detection via LED stripe and projection
Duration	2 min	1 min	1 min	1 min
Sequence	Initial procedure	First test	Randomized sequence	

In the AV2PAS experiment the test person is immersed in the situation where he/she stands inside an autonomous public transport vehicle. The aforementioned tutorial precedes the actual scenarios to familiarize the test person with the VR environment. The actual test consists of a virtual ride with the AV, where various concepts for providing information are deployed. This includes displaying the AV's intention as well as the AV's detection system.

During the ride inside the vehicle, the test person has to state the level of anxiety felt. The experiment is followed by qualitative interviews where the test person states their levels of (dis-)comfort during the experiment. Analysis of the collected data can determine what information is most effective for preventing anxiety while travelling by autonomous public transportation.

In the first AV2PAS scenario, no additional information is shown inside the vehicle. This is equivalent to information provided in manually driven transportation today. Furthermore, travel information related to public transport, like boarding and alighting information, stations, etc., is excluded to rule out possible distortions regarding the experiment's results. This applies to all AV2PAS scenarios (see Table 2).

In the second AV2PAS scenario, the AV's intention is displayed via an LED stripe, or a screen underneath the windshield. The AV's intended direction of motion is displayed with a light indicator. Additionally, the shape of the light indicator signals acceleration and deceleration (see Table 2).

In the third AV2PAS scenario, the AV's detection system is displayed via an LED stripe, or a screen underneath the windshield. Pedestrians or cyclists that are located within the AV's detection range are displayed to passengers (and the test person) with a light indicator. Additionally, the position of the light(s) on the LED stripe indicates the location of the detected object(s) (see Table 2).

The fourth AV2PAS scenario is a combination of intention (second scenario) and detection (third scenario). The combination of technology utilized (LED stripe and screen) is deployed randomly. This means that the first instance has the intention displayed via a screen, while the detection system is displayed via the LED stripe, and vice versa (see Table 2).

Within each scenario, the various tests are conducted in a random sequence to rule out distorted results caused by the testing order. Furthermore, scenarios two and three are conducted in a randomized sequence. Since the fourth scenario is a combination of the second and third scenario, it is always conducted last (see Table 3).

Table 2: Overview of AV2PAS Experiment

Scenario	0	1	2	3	4
Concept	Tutorial	No information provided	Indication of driving intention (e.g. AV is decelerating)	Indication of pedestrian detection (e.g. AV has detected a pedestrian or other road users)	Indication of driving intention (e.g. AV is decelerating) and pedestrian detection (e.g. AV has detected a pedestrian or other road users)
Duration	2 min	1 min	1 min	1 min	1 min
Sequence	Initial procedure	First test	Randomized sequence		Last test

5. Discussion and Outlook

Compared to other methods for data collection (e.g. real-life experiments and computer-based simulations), Virtual Reality has its advantages and drawbacks.

The main advantage of VR – as already stated before – is its ability to test design concepts (e.g. HMI) and collect data in complex scenarios with minimal effort and maximal safety.

Furthermore, since a setting similar to a scientific laboratory is used within the VR method, disruptive factors that could occur in real-life conditions (e.g. vibrations and temperature fluctuations) can be minimized. Consequently, depending on the scenario, the VR method can collect even more reliable data than tests in real-life conditions.

Limitations of the described VR experiments are related to the degree of immersion and the absence of haptic feedback. In this respect, experiments conducted in real-life conditions have the advantage. According to Chalmers (2013), “facts”, as a scientific term, can only be gathered through real-life experiments. However, when physical prototypes are neither available nor technically feasible, the VR method is a good alternative for initial investigation.

When it comes to pedestrian or passenger behaviour within specific built environments, computer-based simulation is another channel that can be used for data collection. Instead of conducting real-life experiments, software simulates them, such as crowd behaviour for the design of public transportation facilities (Essadeq, 2016), or for optimizing emergency evacuation within buildings (Zhou, 2010). Depending on the scenario, the time and financial resources required for a computer-based simulation can be even more efficient than the VR method. Nevertheless, simulations have drawbacks relating to the complexity of modelling the social and psychological factors that drive decision-making processes in human beings. Results regarding these factors are either neglected or highly simplified (Luo, 2008). Since the VR method involves actual human beings in the experiments, sociological and psychological factors can be investigated. The VR methodology can be used beyond measuring the efficiency of an HMI concept for AVs. Future research could use VR for investigating the general user perception of AVs and therefore explore how to promote user acceptance of AVs.

As outlook to the presented study, the tested concepts can be transferred to other fields of investigation. Indeed, since the HMI concepts in the AV to pedestrian scenario focuses on autonomous driving in general, these concepts can be transferred to the private transportation sector. This would have the advantage of standardizing procedures regarding the interaction between pedestrians and AVs. Global standards in the automotive industry already exist, for instance, the ISO/TS 16949. This standard defines system requirements inter alia for design, development and production (ISO/TS, 2009). The communication with AVs could enhance this standard.

Considering the AV to pedestrian scenario, HMI cannot be the exclusive tool to solve this emerging communication problem. This issue has to be tackled from the governmental side within specific regulatory frameworks. These could, for instance, stipulate how pedestrians and AVs have to interact, especially in scenarios like jaywalking, where clear regulations have to be published. Millard-Ball (2016) suggests that legislation could specify that AV manufacturers are not liable for any collisions caused by jaywalkers. Furthermore, scenarios like this could be improved with infrastructure. Segregation between pedestrians and vehicles with fences and over-head bridges could further hinder pedestrians from jaywalking (Millard-Ball, 2016).

6. Conclusion

Using Virtual Reality as experimental method is an approach that provides reliable data with minimal cost and time while maximizing safety. This method is an advantageous alternative to real-life experiments, especially in situations where a prototype is not available or when the experiment could potentially be dangerous for the test person(s). Representative traffic situations with only manually-driven cars and AVs are very complex to recreate in real-life conditions. Thus, the VR method is particularly beneficial in the field of autonomous vehicles. Furthermore, concepts can be validated with real-time observation without the need to build cost- and time-consuming physical prototypes or mock-ups. For the user-centred design approach of industrial designers, the VR method carries the advantage of investigating the behaviour of real persons through immersion where simulations only consider agent-based approaches.

This is aligned with recent findings regarding design methods (Van der Bijl-Brouwer & Dorst, 2017) since the one proposed in this paper merges aspects of human-centred design (i.e., engagement of human beings and understanding of their needs) with design innovation process, which encourages the development of new tools and methods for strategic innovation.

As a next step, sensors like EEG (Electroencephalogram), GSR (Galvanic Skin Response) or Heart Rate measurements will be included in the experiment setup. With these sensors, arousal and valence levels of the test persons can be measured while conducting the experiments. These measurements will support the data collection using current methods and make results increasingly reliable in the future.

7. Acknowledgment

TUMCREATE Ltd. is a joint research institution between the Nanyang Technological University Singapore and the Technical University Munich, Germany. TUMCREATE Ltd. is supported by the Singapore's National Research Foundation, Singapore, under its Campus for Research Excellence And Technological Enterprise (CREATE) program. The presented work is part of the Phase 2 investigation "Towards the Ultimate Public Transport" within the team "Design for Autonomous Mobility".

References

Berg, L. P., & Vance, J. M. (2017). Industry use of virtual reality in product design and manufacturing: a survey. *Virtual Reality, 21*(1), 1-17, Doi: 10.1007/s10055-016-0293-9

BMW, (2016). The future starts now: The BMW Vision next 100. Retrieved from: https://www.bmw.in/en/topics/bmw-insights/bmw-next-100/bmw-vision.next-100.html (21.08.2017)

Chalmers, A. (2013). What is this thing called science, University of Queensland Press, St. Lucia

Clamann, M., et. al. (2016). "Evaluation of Vehicle-to-Pedestrian Communication Displays for Autonomous Vehicles", *96th Annual Transportation Research Board Meeting*, Washington DC

Dong, X. et. al. (2017). Transit user perceptions of driverless buses, Springer Science + Business Media New York, New York

Essadeq, I., et al. (2016). Modelling passenger congestion in transit system – benchmark and three case studies, *6th Transport Research Arena (18-21.04.2016)*

IHS Automotive, (2014). Automotive Technology Research; Emerging Technologies – Autonomous Cars-Not if, but when. Retrieved from: http://news.ihsmarkit.com/press-release/automotive/self-driving-cars-moving-industrys-drivers-seat (14.08.2017)

Intel, Strategy Analytics, (2017). Accelerating the Future: The Economic Impact of the Emerging Passenger Economy. Retrieved from https://newsroom.intel.com/newsroom/wp-content/uploads/sites/11/2017/05/passenger-economy.pdf (25.09.2017)

ISO/TS 16949 (2009). Quality management systems -- Particular requirements for the application of ISO 9001:2008 for automotive production and relevant service part organizations, International Organization for Standardization, Geneva, Switzerland

Giffi, V. et al. (2017). Deloitte Study: Fact, Fiction and Fear Cloud Future of Autonomous Vehicles in the Minds of Consumers, Deloitte, New York

Luo, L. et al. (2008). Agent-based human behaviour modelling for crowd simulation, *Comp. Anim. Virtual Worlds 2008*, 19, pp 271-281, Doi: 10.1002/cav.238

Mercedes, (2015). Der Mercedes-Benz F 015 Luxury in Motion. Retrieved from https://www.mercedes-benz.com (21.08.2017)

Mihelj, M. et al. (2014). Virtual Reality Technology and Applications, Springer, Dodrecht

Millard-Ball, A. (2016). Pedestrians, Autonomous Vehicles and Cities. *Journal of Planning Education and Research,* pp 1-7, Doi: 10.1177/0739456X16675674

Nissan, (2015). Nissan IDS Concept: Nissan's vision for the future of EVs and autonomous driving. Retrieved from http://www.nissan-global.com (21.08.2017)

SAE International, (2016). Taxonomy and Definitions of Terms Related to Driving Automation Systems for On-Road Motor Vehicles. Retrieved from www.sae.org (21.08.2017)

Schneemann, F. (2016). "Analysing Driver-Pedestrian Interaction at Crosswalks: A Contribution to Autonomous Driving in Urban Environments", *2016 IEEE Intelligent Vehicles Symposium, Vol. VI, pp 38-42,* Doi: 10.1109/IVS.2016.7535361

Shoettle, B. et. al. (2014). A survey of public opinion about autonomous and self-driving vehicles in the U.S., the U.K., and Australia. The University of Michigan, Michigan.

Šucha, M. (2014), Fit to drive: 8th International Traffic Expert Congress, Warsaw

The New York Times, (2016). Inside the self-driving Tesla fatal accident. The New York Times. Retrieved from https://www.nytimes.com/interactive/2016/07/01/business/inside-tesla-accident.html (23.08.2017)

Van der Bijl-Brouwer, M., Dorst, K. (2017). Advancing the strategic impact of human-centred design, *Design Studies,* Elsevier, Ltd., Doi: 10.1016/j.destud.2017.06.003

Zhou, S. et al. (2010). Crowd Modeling and Simulation Technologies, *ACM Transactions on Modeling and Computer Simulation (TOMACS), Vol. 20, 4(20),* Doi: 10.1145/1842722.1842725