A review of the interactions between Autonomous Vehicles and Vulnerable Road Users

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Abstract

Recent technological advancements have led to a race in Autonomous Vehicle (AV) developments. One of the issues that is most critical when considering the circulation driverless AVs in roads is their interaction with Vulnerable Road Users (VRUs). The present research aims to investigate the issues of interaction between AVs and VRUs. A literature review from recently published studies around the globe was conducted in order to assess the available technologies and locate possible future trends. The first section examines the topic from the side of AVs and automation technology overall, while the second section approaches issues from the VRU side, such as trust and acceptance. Each section is further divided by examining how different levels of automation will affect the interaction between AVs and VRUs. Results indicate that while low level automation technologies are already proving beneficial, higher level automation seems to be concentrating on compiling AI algorithms that mimic several distinguishing and decision-making functions of the human brain in order to prioritize providing VRUs with the increased attention they merit. Lastly, research on the detection of mobility-impaired VRUs such as manual or electric-powered wheelchair users seems to be lacking.

Keywords

Autonomous vehicles; vulnerable road users; interaction; literature review; automation levels.

1. Introduction

The expected arrival of autonomous vehicles (AVs) has triggered intense research within the transport community in recent years. AVs are expected to be developed with the purpose of gradually transferring all navigation and vehicle control from human drivers to AIs, as Levels of automation increase [1].

One of the major fronts of AV development, and at the same time a field of algorithm testing and considerable road safety study efforts is the interaction of AVs with vulnerable road users (VRUs). VRUs include children, elderly, people with impairments and disabilities, all of whom have a right to share the roads, and a safe environment must be provided for them as well. Despite great progress in the recent years, major limitations of AVs include accurate navigation, efficiency and reliability issues, as well as the absence of a robust legal framework; lack of social acceptance is a factor as well [2]. Furthermore, VRUs are not yet critical in present frameworks of HMI (human-machine interaction), which are rather based on social norms that have been established with human drivers controlling the vehicles [3]. Thus the interactions of AVs are a justified source of skepticism and hinder the onset of AVs. On the other hand, if VRUs have the knowledge that AVs are more safely operated, this would lead to improved confidence and overall quality of life [4].

When it comes to sharing the road, there can be no other arrangement than the recognition of VRUs under all reasonable circumstances, with no specific adaptations on their part (such as reflective clothing). The behavior of different VRUs must be predicted and their intentions should be anticipated by AVs. The pessimistic alternative presenting an arrangement where planning prioritizes AV passengers over VRUs, favoring the needs of more wealthy road users, has also been posed in the literature [5], but it is not commonly anticipated amongst researchers, who assume VRU care and prioritization.

This applies especially in 'close quarters' environments such as very dense urban centers, highly used parking spaces or any other places where large volumes of pedestrians or other VRUs mingle with vehicles. Past research has shown pedestrians to be at fault in 80% of pedestrian crashes at intersections [6], which demonstrates the need to safeguard them despite any possible improper behaviour on their part. Liu & Khattak [7] describe driving on local roads to be more volatile in terms of variance of accelerations, in part due to the presence of VRUs and related distractions.

This is an especially critical area, since it appears very challenging to predict behavioral intentions of pedestrians and cyclists by current technology. If these road users display different behaviors against AVs compared to conventional vehicles, then current knowledge might be ineffective for the development of algorithms that would enhance safety [8].

The present research aims to investigate the interaction between AVs and VRUs, a topic of critical importance for consideration during the following years. This is not only due to the susceptibility of VRUs to injury and mortality: The first interactions between AVs and VRUs will affect the transition to automation tremendously. Public perception and acceptance will be affecting the strategy and policies of the automobile industry, which will increase or decrease the demand and pressure to authorities for the creation of the appropriate framework for autonomous vehicles, ultimately affecting the transition itself.

This review is structured as follows: The first section examines the topic from the side of AVs and automation technology overall, while the second section approaches issues from the VRU side, such as trust and acceptance. Each section is further divided by examining how different levels of automation will affect the interaction between AVs and VRUs. The discussion concludes this research offering conclusions and directions of future developments.

There was an intent to include mostly recent studies, namely those published within ten years. Furthermore, studies were included from around the globe representing different areas, in order to better capture the trends of the interaction between AVs and VRUs globally. Relevant studies discussing this interaction were located using scientific databases and repositories (Science Direct/Scopus, Google Scholar, and TRID); the authors endeavored, to the extent of their knowledge, to include all available studies on the topic.

As an overview, results indicate that while low level automation technologies are already proving beneficial, higher level automation seems to be concentrating on compiling AI algorithms that mimic several distinguishing and decision-making functions of the human brain in order to prioritize VRUs. The closing section refers to the limitations of the current review and suggest some recommendations for future research to be done in order to fill existing gaps.

2. Considering the AV side

As an indication of the advances of AV technology, it has been proposed that AVs should not be treated as tools or objects but rather as intelligent agents that will have freedom of movement, while VRUs and humans overall currently possess no experience on how to treat them [9].

To test the functionality of AVs, since legal frameworks are nascent at best and non-existent at worst, Field Operational Tests (FOTs) are usually employed. During the last years, FOTs have been conducted in several countries (in Europe, the US, Japan, Australia, and other countries) to test Intelligent Transport Systems. There are, however, considerable hurdles in data sharing between companies, mainly due to competition, privacy issues, and operational costs. Despite that, data sharing is expected to facilitate more and more efficient learning [10].

Fagnant and Kockelman [11] estimate for the US that for AV penetration rates of 10%, 50% and 90%, the authors project a corresponding 1.100, 9.600 and 21.700 lives saved (in the US) per year. However, these estimates include several assumptions involving AV assimilation into the road network and how it might actually work, such as changes in market penetration shares, vehicle miles travelled, AV technology costs, and appropriate discount rates for net present value calculations. VRU crashes with motor vehicles could be assumed to enjoy only a portion of the respective AV safety benefits, since at least one of the crash parties (VRUs) will not rely on automation technology. A similar point raised in research is that even a perfectly functional AV cannot overcome the limitations of physics, such as stopping distance required [12], therefore crash reductions are expected to be considerable but not absolute.

2.1 Levels 1 & 2

The specific demands of effective VRU interaction should be taken into account even at the lower levels of automation.

As Soquet et al. [13] highlight, a main issue in autonomous navigation is free space estimation. The respective study proposes using a stereovision system to extract such areas, however map density and large computation times were cited as areas warranting improvement.

When studying pedestrian detection, Krotosky & Trivedi [14] compared infrared and color stereo systems. Given that the initial levels of accuracy were considered high, further assessment was conducted on the basis of classifying detected obstacles into pedestrian and non-pedestrian regions. Final results of that study showed that a two camera, cross-spectral stereo solution to obtain the depth, color and thermal features desirable for a pedestrian detection system.

Thermal camera performance as Advanced Driver Assistance Systems (ADAS) have been tested in other studies, such as the one by Peláez et al. [15]. The authors propose an algorithm that utilized a thermal stereo system to analyze the thermal features of the road complemented by the depth information obtained from a disparity map. A set of images under different weather conditions was used to classify vision fields as road surface and non-road surface, with true positive results being more than 83% in all scenarios apart from a specific summer case, with the authors explaining that further improvements are required.

VRUs have an important role to play when considering technologies parallel to complete automation, such as connected vehicle applications. Liu & Khattak [7] investigated connected vehicle technologies transmitting data through V2V and V2I applications. They extracted information from driving that could be provided to drivers as instantaneous feedback about surrounding dangers. They highlighted complex intersections as critical areas, as demonstrated by collected data from instrumented vehicles. For instance, a six-way intersection consisting of three two-way roads with pedestrian sidewalks generated consecutive separate warnings and control assists to the driver. A study by Rosen [16] modeled an autonomous emergency brake (AEB) system and simulated real vehicle-VRU crashes (543 car-to-pedestrian and 607 car-to-bicyclist collisions). AEB performance was examined when some system parameters varied. While the system was projected to have high effectiveness in mitigating fatalities and injuries, functionality was found to be considerably restricted in darkness and high speeds. Additionally, effectiveness was highly sensitive to the tuning of brake and acceleration timing.

2.2. Level 3

Already from level 3 onwards, the NHTSA determined that the industry should take into account the manner in which AVs will signal the intentions of the vehicle to the road environment, including VRUs [17]. The Euro NCAP has designated pedestrian warning/detection systems as essential safety systems to be applied from 2016 onwards, and in 2018 has introduced more targeted scenarios (longitudinal pedestrian scenario, cyclist scenarios, low light assessment etc.) for VRU detections [18]. Banks et al. [19] note that this direction enables the investigation of systems such as pedestrian emergency braking on driver behaviour before mass production begins. They explore how the increases of automation level, changes the cognition of information, even considering a single VRU related system such as pedestrian detection.

Dehais et al. [20] hypothesized that human operation conflicting with automation will reduce human attention. To this end, they experimented with participants controlling a real unmanned ground vehicle, and in the majority of participants typical 'automation surprise' situations were provoked, though the small sample limits transferability of the results. More pertinent to the subject, the authors also highlight a rather counter-intuitive possibility: they claim that since information processing will be conducted independently by systems such as pedestrian detection, drivers might become bored or fatigued, and low activity levels might result in episodes of mental under-load of drivers. This result is within the framework laid by Brookhuis & de Waard [21]. Their study reaches the conclusion that mental workload should be optimized between high and low extremes to avoid subpar driving performance.

In Owens et al. [22] a series of researchers presented studies relevant to VRU and AV interaction. Some highlights are the following: The Automated Vehicle Interaction Principles (AVIP) project entails an outward-facing LED light bar affixed to the top of the vehicle windshield that uses distinct patterns of light to communicate the vehicle's intent to pedestrians. Initial results showed that such interfaces may reduce pedestrian stress and uncertainty associated with absent or distracted drivers. It is also mentioned that pedestrians overestimate their own visibility to drivers as shown by past research [23, 24] and that this confidence, along with social factors, can pose a similar challenge to AV systems in the future. The importance of integrating VRU traditional cues and gestures was discussed as well. The integration of pedestrians, in coexistence with all other road users, is under research in the Multi-modal Intelligent Traffic Signal System (MMITSS) project, which explores dynamic mobility applications that can enable safe flows of pedestrians in automated intersections. Finally, the PROactive Safety for Pedestrians and CyclisTs (PROSPECT) project was stated to research advanced machine learning techniques for vision sensors, among other goals, and to validate the findings in demonstration vehicles [25, 26].

2.3. Levels 4 & 5

At these levels automation is considered advanced enough to allow handing total or near-total control of the vehicles to AI algorithms. It should be mentioned that detection delays vary as the VRU navigation task begins, ends or switches between walking or standing [2]. The automobile industry has proposed several such displays or interfaces [27, 28] for AV-to-pedestrian communication.

Several technical approaches have been explored for analyzing the handling of interactions from the side of the AVs. There have been propositions for the development of models that assume a limited (finite) set of unknown intentions from the interacting actors using the principles of Markovian decision processes. In practice, such algorithms have been shown as more effective in decision making processes [29]. Katrakazas et al. [30] investigate planning algorithms that account for the reasoning abilities of humans and integrate them in behavioural models. The resulting predictions will either forecast trajectories or anticipate other actions such as road crossings.

When examining the ethics of an automated world, the argument has been made that a fully automated vehicle should be programmed to weigh occupant protection and select the course with the least societal impact (for instance collide with a pedestrian to injure them slightly over veering to the side and greatly injuring the AV occupants). This requires the AV to discern and factor in whether VRUs have adequate protection at the time, such as cyclist helmets [31]. All in all, in such cases the AV will observe and judge the situation in a manner not dissimilar to a human brain.

3. Considering the VRU side

3.1 Trust and Acceptance

A distinctive aspect that is typically found in the side of VRUs (and not in AVs) is the element of trust and acceptance. VRUs need to feel comfortable sharing the road with automated traffic, as considerable research has explored. Furthermore, pedestrians decide to cross based on what they perceive as acceptable gaps. Research has shown that accepted gaps depend on distance from oncoming traffic, as opposed to vehicle velocity, as well as vehicle size [32].

Trust and acceptance already exist in present mixed traffic even without automation after all. Zhao et al. [33] conducted a survival analysis which showed that motor vehicle drivers and non-motor vehicle drivers show different sensitivities to the lateral distance acceptable to vehicle operation. Non-motor vehicle drivers can be assumed to provide more trust to their own approaches to nearby motor vehicles than vice-versa. If the balance of this state of affairs is disturbed with the introduction of automated vehicles, it could be possible to expect bicyclists requiring more space to feel secure on the roads on a psychological level.

As discussed when considering the AV side, different social norms cause VRUs to display different behaviour. From experience from North America, it has been found that pedestrians display differences in driver yielding culture among communities, and show higher rates of yielding on roadways that are narrow and with lower speeds. Crosswalk law enforcement, which influences culture, is rare in most areas [34].

The CATS project involved initial testing and subsequent pilot transport of 1600 participants in Lausanne, France. After using the custom vehicles, amongst other answers, 39% of participants claimed that they were willing to use autonomous vehicles regularly in the future, while only 5% of respondents were reluctant to do so. The absence of a driver was not perceived as a problem by 78% of respondents [35].

A research on public opinion after AV operation in La Rochelle, France showed that 25% of the participants supported that AVs would be safer than conventional vehicles. On the contrary, 39% anticipated that the introduction of AVs would worsen safety levels, while 46% claimed there would be no difference. Furthermore, circa two out of three people would consider selecting automated buses if they were offered as alternative alongside conventional buses, which is an interesting insight on the automation of public transport [36].

Brar and Caulfield [37] investigated public opinion on the impact of AVs to pedestrian safety. They conducted an online survey and reported that while pedestrians have a positive outlook on automation technologies, they did show hesitation and concern about various relevant automation issues. Concerns included the interaction of AVs with conventional vehicles and VRUs, as well as the possibility of system or equipment failure, security of vehicles, and data privacy.

3.2. Levels 1, 2 & 3

Low level automation, which would mainly augment human driving, seems to be easily accepted by VRUs, if noticed at all. However, Sparrow & Howard [38] raise an important issue by stating that any systems requiring human supervision to function will include increased amounts of risks and are not likely to satisfy consumer needs. Therefore penetration rates of AVs might be affected even in low levels of automation.

Concerning cyclists specifically, the European Cyclists' Federation (ECF) has stated that there are basic AV technologies such as Intelligent Speed Assistance, Automatic Emergency Braking for cyclists and blind spot detection for large vehicles that are desirable and must be applied as soon as possible. They argue the existence of both safety issues but also potential benefits of fully automated AVs, making vision zero a real possibility. The ECF highlights the lack of understanding of how Connected Intelligent Transport Systems will integrate non-equipped modes such as cycling and walking, a research gap which will need to be addressed soon. The possible mass modal shift towards automation and the resulting congestion is also underlined, with hints to future funding of cycling and walking [39].

3.3. Levels 4 & 5

It has been proposed that the active role of humans will never leave transport systems even after Level 4+ AVs are exclusive, given the presence of VRUs [3].

Thought has been given to exploring the willingness of pedestrians to cross the street. In addition, their emotional state has been investigated when interacting with automated vehicles. Results of a field experiment have shown that, unsurprisingly, pedestrians' willingness to cross the street decreases when faced with an inattentive driver [40,41]. The study assessed emotional experiences from pedestrians using a Self-assessment manikin tool and verbal comments. The authors conclude that an alternative provision of external information to pedestrians is required (for instance a vehicle interface). These possibilities have already been explored in relevant projects such as GRAIL (Green Assistant Interfacing Light) [1]. However, a common and standardized approach that VRUs could be familiarized with is both necessary and absent at present.

An example of the design for such approaches can be found in the literature. Clamann et al. [42] evaluated the effectiveness of various methods of presenting AV-to-pedestrian street crossing information, using a forward-facing display in a naturalistic setting. They found that Individual differences, including age, gender, crossing location and conscientiousness were predictive of safe crossing decisions. Further to that, pedestrians still relied on traditional interactions with drivers, but nonetheless supported additional information being relayed to them from displays. Similarly, Rothenbücher et al. [43] conducted a proof-of-concept study where pedestrians encountered a seemingly driverless vehicle at a crosswalk. Pedestrians were reported to interact with the vehicle without problem, claiming that study participants were comfortable with the absence of communication cues. The authors attribute that to pedestrian experience with situations where the driver is not visible (for instance during nighttime). The study does report possible participant selection bias, however. On the other hand, Keferböck & Riener [44] claim that it is important to substitute the traditional driver-pedestrian communication with the recognition of pedestrian cues (signs, gestures) by AVs. AV-to-pedestrian communication will involve using visual feedback on windscreen, bonnet or headlights.

Several methodological approaches have been tested for the field of AV-VRU interaction. Millard-Ball [45] uses game theory to analyze the interactions between pedestrians and autonomous vehicles, with a focus on yielding at crosswalks. The analyses suggest that pedestrians will take advantage of the very conservative programming of AVs, thus shifting to pedestrian oriented urban neighborhoods. This might in turn lead to smaller penetration rates for AVs, as transitions will be cumbersome for their passengers. It should be noted that the author uses a predictive model derived from theoretical Nash equilibria; in practice the odds may be different but the overall idea remains unchanged. Studying VRU behaviour might be difficult, especially in the absence of functional AV prototypes. For that reason, Habibovic et al. [46] explored three versions of the Wizard of Oz approach in order to collect data of interactions between drivers and pedestrians on one side and AVs on the other. In the respective study, 13 pedestrians were faced with different vehicle and driver behaviours. Initial results showed that pedestrian willingness to cross decreased with inattentive drivers. The authors claim that to sustain perceived safety with pedestrians, outside signals would be required.

A recent study also utilized the Wizard of Oz approach in order to examine pedestrian crossing decisions when interacting with an AV. In field conditions, a road section was isolated and a custom vehicle was piloted by joystick by the passenger seat occupant, while the 'driver' was seemingly inattentive via several different scenarios such as newspaper reading; there were visible warning "self-driving" signs as well. Measurement results indicated no statistically significant differences between vehicle conditions concerning acceptable gap or stress levels for pedestrians, though the latter did report being influenced by these features. The number of participants was limited, however, and a number of them might have recognized the 'deception' of the Wizard of Oz approach [47].

A set of some of the characteristics of the examined studies can be found on Table 1. It can be seen that both the AV and VRU sides have been investigated, and that field setups that provide actual data are favored by researchers, despite being more resource and time consuming.

4. Discussion

Currently, it has been established that low-level (2 or less) automation-ADAS technologies provide positive impacts on road safety, improving driver performance characteristics and providing useful information. As such, there will be continuous implementations in the industry that will lead to the improvements of vehicles still operated by human drivers. This will apply to interactions with VRUs as well, providing early detection, warning, automated braking etc.

When advancing further, however, in automation levels of 3 or higher, there is still a lot of uncertainty when trying to predict AV-VRU interactions from the present state of affairs, especially considering the multitudes of different scenarios that VRUs can face. Currently the collective efforts of developers seems to be concentrating on compiling AI algorithms that mimic several distinguishing and decision-making functions of the human brain, which will simulate artificial drivers and give a wide berth and priority to VRUs.

The exact handling and overall AV performance under different conditions such as weather, road class, lighting, traffic conditions etc. will be dependent on their programming. Since there is no official base to coordinate AV manufacturers, it is reasonable to expect differences in driving behaviour between manufacturers. For the first time we might see vehicles of Make A driving more conservatively than those of Make B. VRU-AV interaction can happen independently of all these conditions and several different outcomes will be observed, at least during the initial phase of full automation. All of this will resonate with the public and the market will adjust to the performance of each AV, which will affect penetration rates and again change the equilibrium.

Table 1. Study characteristics considering AV-VRU interaction

Study characteristics			**Investigated side**		**Data used**			**Parameters examined**	
Author(s)	Year	Country	AV	VRU	Field data	Simulated data/ Questionnaire	No data	VRU recognition/ warning from AV	AV trust/ acceptance from VRU
Bandyopadhyay et al.	2013	Singapore	●		●	●		●	●
Banks et al.	2014	United Kingdom	●				●	●	
Brar & Caulfield	2017	Ireland		●		●			●
Christie et al.	2015	Switzerland		●	●				●
Clamann et al.	2017	United States		●	●				
Dehais et al.	2012	France		●	●			●	
Habibovic et al.	2016	Sweden		●	●				●
Katrakazas et al.	2015	United Kingdom	●						
Krotosky & Trivedi	2007	United States	●		●			●	
Liu & Khattak	2016	United States	●		●			●	
Millard-Ball	2016	United States		●			●		●
Palmeiro et al.	2018	The Netherlands		●	●				●
Rosen	2013	Sweden	●			●		●	
Rothenbucher et al.	2016	United States		●	●			●	

Furthermore, there exist considerable knowledge gaps and lack of analyses of some of the existing VRU categories. Apart from ordinary pedestrians and cyclists, VRUs also encompass road users with mobility impairments, such as people in manual wheelchairs or electric-powered wheelchairs (EPWs) and similar devices. These impaired road users typically move much slower and with less nimbleness than pedestrians and cyclists, and their handling of AVs will need to be examined by dedicated studies before full automation can become a reality.

Naturally, there are some limitations to the current research. It is obvious that from a road safety perspective, there can be no hard evidence until AVs roll out of the factory and operate on real-world conditions. A large section of the science of road safety has been established on analyzing past data to determine crash correlation and causation parameters. On the technical part, until data from real conditions are available, there can be no solid knowledge of which parameters provide the most useful insights (e.g. pedestrian posture, gaze direction etc.), which will then lead to new challenges regarding their collection. On the societal part, the magnitude of the impact of AVs on road crashes, both actual and perceived, remains to be seen.

There are hard bets to be won, as any lapse or malfunction against VRUs will generate negative outlook to the public which will be disproportionately high compared to any crash between conventional vehicles and VRUs. This might set back automation public acceptance, delaying official and legal framework developments and ultimately AV penetration rates.

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References

1. SAE International (2016). Standard J3016: Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles (revised J3016: Sept 2016).
2. Sotelo, M.A. (2017). Cooperative Autonomous Driving and Interaction with Vulnerable Road Users. 9th Workshop on Planning, Perception, and Navigation for Intelligent Vehicles. Vancouver, Canada, 24th Sept. 2017
3. Saleh, K., Hossny, M., & Nahavandi, S. (2017, April). Towards trusted autonomous vehicles from vulnerable road users perspective. In Systems Conference (SysCon), 2017 Annual IEEE International (pp. 1-7). IEEE.
4. Alessandrini, A., Campagna, A., Delle Site, P., Filippi, F., & Persia, L. (2015). Automated vehicles and the rethinking of mobility and cities. Transportation Research Procedia, 5, 145-160.
5. Litman, T. (2017). Autonomous vehicle implementation predictions. Victoria, Canada: Victoria Transport Policy Institute.
6. Lee, C., & Abdel-Aty, M. (2005). Comprehensive analysis of vehicle–pedestrian crashes at intersections in Florida. Accident Analysis & Prevention, 37(4), 775-786.
7. Liu, J., & Khattak, A. J. (2016). Delivering improved alerts, warnings, and control assistance using basic safety messages transmitted between connected vehicles. Transportation research part C: emerging technologies, 68, 83-100.
8. Vissers, L., Van der Kint, S., Van Schagen, I., & Hagenzieker, M. (2016). Safe interaction between cyclists, pedestrians and automated vehicles. What do we know and what do we need to know?. SWOV Institute for Road Safety Research, the Netherlands.
9. Müller, L., Risto, M., & Emmenegger, C. (2016, September). The social behavior of autonomous vehicles. In Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing: Adjunct (pp. 686-689). ACM.
10. Barnard, Y. F., Innamaa, S., Koskinen, S., Gellerman, H., Svanberg, E., & Chen, H. (2016, June). Methodology for field operational tests of automated vehicles. In Transport research procedia (Vol. 14, pp. 2188-2196). Elsevier.
11. Fagnant, D. J., & Kockelman, K. (2015). Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. Transportation Research Part A: Policy and Practice, 77, 167-181.
12. Sivak, M., & Schoettle, B. (2015). Road safety with self-driving vehicles: General limitations and road sharing with conventional vehicles.
13. Soquet, N., Perrollaz, M., Labayrade, R., & Aubert, D. (2007). Free space estimation for autonomous navigation. In 5th International Conference on Computer Vision Systems.
14. Krotosky, S. J., & Trivedi, M. M. (2007). A comparison of color and infrared stereo approaches to pedestrian detection. In Intelligent Vehicles Symposium, 2007 IEEE (pp. 81-86). IEEE.
15. Peláez, G. A., Bacara, D., de la Escalera, A., García, F., & Olaverri-Monreal, C. (2015, June). Road detection with thermal cameras through 3D information. In Intelligent Vehicles Symposium (IV), 2015 IEEE (pp. 255-260). IEEE.
16. Rosen, E. (2013). Autonomous emergency braking for vulnerable road users. In Proceedings of IRCOBI conference (pp. 618-627).
17. National Highway Traffic Safety Administration, 2016. Federal Automated Vehicles Policy: Accelerating the Next Revolution in Roadway Safety. National Highway Traffic Safety Administration DOT HS 812, 329.
18. Williams, A. (2017). Euro NCAP 2018 5-Star Requirements, Asta Zero Testers' Day Presentation, 25th April 2017.
19. Banks, V. A., Stanton, N. A., & Harvey, C. (2014). Sub-systems on the road to vehicle automation: Hands and feet free but not 'mind' free driving. Safety science, 62, 505-514.
20. Dehais, F., Causse, M., Vachon, F., & Tremblay, S. (2012). Cognitive conflict in human–automation interactions: a psychophysiological study. Applied ergonomics, 43(3), 588-595.
21. Brookhuis, K. A., & de Waard, D. (2010). Monitoring drivers' mental workload in driving simulators using physiological measures. Accident Analysis & Prevention, 42(3), 898-903.
22. Owens, J. M., Greene-Roesel, R., Habibovic, A., Head, L., & Apricio, A. (2018). Reducing Conflict Between Vulnerable Road Users and Automated Vehicles. In Road Vehicle Automation 4 (pp. 69-75). Springer, Cham.
23. Tyrrell, R. A., Wood, J. M., & Carberry, T. P. (2004). On-road measures of pedestrians' estimates of their own nighttime conspicuity. Journal of Safety Research, 35(5), 483-490.
24. Wood, J. M., Tyrrell, R. A., Marszalek, R. P., Lacherez, P. F., Carberry, T. P., Chu, B. S., & King, M. J. (2010). Cyclist visibility at night: perceptions of visibility do not necessarily match reality. Journal of the Australasian College of Road Safety, 21(3), 56-60.

25. Wisch, M., Lerner, M., Schneider, A., Juhász, J., Attila, G., Kovaceva, J., Bálint, A., Lindman, M. (2016). Accident Analysis, Naturalistic Observations and Project Implications – Part A: Accident data analyses. Deliverable 2.1 of the PROSPECT project.
26. Merenda, C., Kim, H., Gabbard, J. L., Leong, S., Large, D. R., & Burnett, G. (2017, September). Did You See Me?: Assessing Perceptual vs. Real Driving Gains Across Multi-Modal Pedestrian Alert Systems. In Proceedings of the 9th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 40-49). ACM.
27. Urmson, C, I. Mahon, D. Dolgov, and J. Zhu. Pedestrian Notifications. Google, Inc., assignee. Patent US 9196164 B1. 24, 2015.
28. Nissan IDS Concept: Nissan's Vision for the Future of EVs and Autonomous Driving [Press Release]. 2015. Available online (accessed 25/08/2018): https://newsroom.nissan-europe.com/eu/en-gb/media/pressreleases/139047/nissan-ids-concept-nissans-vision-for-the-future-of-evs-and-autonomous-driving1
29. Bandyopadhyay, T., Won, K. S., Frazzoli, E., Hsu, D., Lee, W. S., & Rus, D. (2013). Intention-aware motion planning. In Algorithmic foundations of robotics X (pp. 475-491). Springer, Berlin, Heidelberg.
30. Katrakazas, C., Quddus, M., Chen, W. H., & Deka, L. (2015). Real-time motion planning methods for autonomous on-road driving: State-of-the-art and future research directions. Transportation Research Part C: Emerging Technologies, 60, 416-442.
31. Gerdes, J. C., & Thornton, S. M. (2015). Implementable ethics for autonomous vehicles. In Autonomes fahren (pp. 87-102). Springer Vieweg, Berlin, Heidelberg.
32. Yannis, G., Papadimitriou, E., & Theofilatos, A. (2013). Pedestrian gap acceptance for mid-block street crossing. Transportation planning and technology, 36(5), 450-462.
33. Zhao, F., Guo, H., Wang, W., & Jiang, X. (2015). Modeling lateral interferences between motor vehicles and non-motor vehicles: A survival analysis based approach. Transportation Research Part F: Traffic Psychology and Behaviour.
34. Schneider, R. J., & Sanders, R. L. (2015). Pedestrian safety practitioners' perspectives of driver yielding behavior across North America. Transportation Research Record: Journal of the Transportation Research Board, (2519), 39-50.
35. Christie, D., Koymans, A., Chanard, T., Lasgouttes, J. M., & Kaufmann, V. (2016). Pioneering driverless electric vehicles in Europe: the city automated transport system (CATS). Transportation Research Procedia, 13, 30-39.
36. Piao, J., McDonald, M., Hounsell, N., Graindorge, M., Graindorge, T., & Malhene, N. (2016). Public views towards implementation of automated vehicles in urban areas. Transportation research procedia, 14, 2168-2177.
37. Brar, J. S., & Caulfield, B. (2017, October). Impact of autonomous vehicles on pedestrians' safety. In Intelligent Transportation Systems (ITSC), 2017 IEEE 20th International Conference on (pp. 714-719). IEEE.
38. Sparrow, R., & Howard, M. (2017). When human beings are like drunk robots: Driverless vehicles, ethics, and the future of transport. Transportation Research Part C: Emerging Technologies, 80, 206-215.
39. European Cyclists' Federation – ECF. (2016). Ceri Woolsgrove - Advanced vehicle technologies, autonomous vehicles and cycling.
40. Lagström, T., & Lundgren, V. M. (2015). AVIP-Autonomous vehicles interaction with pedestrians. Master of Science Thesis, Chalmers University of Technology.
41. Lundgren, V. M., Habibovic, A., Andersson, J., Lagström, T., Nilsson, M., Sirkka, A., ... & Saluäär, D. (2017). Will There Be New Communication Needs When Introducing Automated Vehicles to the Urban Context?. In Advances in Human Aspects of Transportation (pp. 485-497). Springer, Cham.
42. Clamann, M., Aubert, M., & Cummings, M. L. (2017). Evaluation of vehicle-to-pedestrian communication displays for autonomous vehicles (No. 17-02119).
43. Rothenbücher, D., Li, J., Sirkin, D., Mok, B., & Ju, W. (2016). Ghost driver: A field study investigating the interaction between pedestrians and driverless vehicles. In Robot and Human Interactive Communication (RO- MAN), 2016 25th IEEE International Symposium on (pp. 795-802). IEEE.
44. Keferböck, F., & Riener, A. (2015). Strategies for negotiation between autonomous vehicles and pedestrians. Mensch und Computer 2015 – Workshopband.
45. Millard-Ball, A. (2018). Pedestrians, autonomous vehicles, and cities. Journal of planning education and research, 38(1), 6-12.
46. Habibovic, A., Andersson, J., Nilsson, M., Lundgren, V. M., & Nilsson, J. (2016, June). Evaluating interactions with non-existing automated vehicles: three Wizard of Oz approaches. In Intelligent Vehicles Symposium (IV), 2016 IEEE (pp. 32-37). IEEE.
47. Palmeiro, A. R., van der Kint, S., Vissers, L., Farah, H., de Winter, J. C., & Hagenzieker, M. (2018). Interaction between pedestrians and automated vehicles: A Wizard of Oz experiment. Transportation Research Part F: Traffic Psychology and Behaviour, 58, 1005-1020.