Journal of the Society of Automotive Engineers Malaysia
Volume 5, Issue 4 (Special Issue), pp 12-21, October 2021
e-ISSN 2550-2239 & ISSN 2600-8092

Technology Review of Automated Emergency Braking Pedestrian System for Selected Vehicles in Global Market

M. A. Meor Said[*1], A. N. Abu Kassim[1], N. H. F. Ismail[2], M. S. F. Mansor[2], M. Z. Che Mustafa[2] and R. Rani[2]

[1]Department of Mechanical Engineering, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak, Malaysia
[2]Safety and Intelligent Drive Department, Research & Development, Perusahaan Otomobil Nasional Berhad, 47600 Shah Alam, Selangor

[*]*Corresponding author: miorazman@utp.edu.my*

REVIEW *Open Access*

Article History:

Received
2 Feb 2021

Accepted
5 Jul 2021

Available online
1 Oct 2021

Abstract – *Accidents involving vehicle and pedestrian has been on the rise, in line with the ever-increasing number of vehicles on the road. Autonomous Emergency Braking (AEB) Pedestrian System is designed to prevent such accidents with the use of sensors and an intelligent system that makes quick action to apply braking force to a vehicle, automatically. The objective of this paper is to report a technology review performed on current Autonomous Emergency Braking Pedestrian systems based on information from owner's manuals, journal papers, and internet resources. 16 different vehicle models that were investigated for this technology review, consisting of a sedan, hatchback, and SUV were investigated based on their differences, similarities, advantages, and disadvantages. Four areas of specifications are highlighted, which are working speed, detection systems, limitations, and special features. Current research done on improving the AEB Pedestrian system is also being reviewed, where Artificial Intelligent tools such as Deep-reinforced Learning are being developed to enhance image processing systems for better detection of Vulnerable Road Users (VRUs), especially in different road conditions, weather, and other circumstances.*

Keywords: Autonomous Emergency Braking Pedestrian, detection, Vulnerable Road User (VRU)

1.0 INTRODUCTION

All over the globe, due to the ever-increasing number of road vehicles, vehicle collisions involving Vulnerable Road Users (VRUs) such as pedestrians, motorcyclists, and cyclists, are on the rise (Chong et al., 2018; Verzosa & Miles, 2016; Ariffin et al., 2010). More than one-fifth of the total road accidents fatality consists of accidents involving pedestrians (Eid & Abu-Zidan, 2015; WHO, 2018).

Accident prevention systems such as Autonomous Emergency Braking (AEB) is designed to minimize or mitigate collision effect, by intelligently applying braking force to achieve safer condition when detecting an object of collision (Baharuddin et al., 2019). Autonomous Emergency Braking or abbreviately known as the AEB system, is high-impact vehicle assistance technology in automatic braking for vehicles at low speed to moderate speed for any obstructions detected by the system (Hulshof et al., 2013). AEB pedestrian is an AEB system that is functioned to prevent or minimize the risk of collision with pedestrians, cyclists, or human-sized animals on the road (Saadé, 2017; Jantan et al., 2020; Said et al., 2021). Before the advancement of the AEB system, the detection mechanism existed in the market for adaptive cruise control features which enable the driver to simulate autopilot experience in terms of vehicle relative speed with proper distance in the safest way at that time of introduction such brand-new driving feature. The working speed of the detection mechanism and vehicle relative speed is the value factors of AEB system performance in total avoidance in any series of collisions possible. Associated with standardized anti-lock braking system (ABS) in coordinating the detection signal for autonomous braking sequence and results may differ depending on the driver's response to the entire unpredictable scenario which activated AEB system. In simple analogy for understanding basis, a sensor for detection, a control system for data interpretation, and a braking system are the functional elements of the AEB system (Anderson et al., 2013).

The objective of this paper is to report a technology review performed on current Autonomous Emergency Braking Pedestrian systems based on information from owner's manuals, journal papers, and internet resources. Detail comparisons of each specification were performed to identify similarities, differences, and limits and highlight the advantages and disadvantages. Table 1 shows 15 different vehicle models that were investigated for this technology review.

2.0 WORKING SPEED VARIATION

Vehicle speed and pedestrian speed are the two important parameters associated with the functionality of an AEB Pedestrian system. Thus, AEB system working speed ranges are specified into two datasets: one for vehicle interrelation and another for pedestrian interaction. Based on the information from vehicles owner's manuals for vehicles in Table 1, working speeds ranging from 4 km/h to 80 km/h are established among all car manufacturers except for 120 km/h, claimed by Perodua for Ativa. It is also evident that the minimum working speed for most Japanese and South Korean cars, is 10 km/h while Nissan Sedan D Altima has a 5 km/h minimum speed. The lowest minimum speed is stated by Toyota for Toyota SUV C CHR. Generally, the AEB pedestrian working speed range is not surpassing the 100 km/h limit due to two operational cost reductions and AEB system effectiveness.

For vehicle speed of detection, it varies for each car manufacturer and its selected cars. Taking an example of the sedan segment, Toyota Sedan C Corolla and Hyundai Sedan C Elantra shared similar detection speeds, ranging from 10 km/h to 180 km/h. Smaller sedan (segment A) represented by Perodua Bezza stated at 4 km/h to 100 km/h and surprisingly, Nissan Altima recorded at 5 km/h to 80 km/h despite being a top tier sedan segment. Another specification to be highlighted in the SUV segment is that almost all shared a similar top speed of more than 100 km/h. Toyota CH-R stated the highest speed at 177 km/h. Only Nissan SUV C X-Trail at a stated top speed below 80 km/h, which is similar to its premium sedan Altima. Nonetheless, the highest value for vehicle speed AEB detection goes to UK Volkswagen

Hatchback C Golf with 200 km/h at its basic variant. These speed detection ranges indicate that the power-to-weight ratio of a vehicle is one of the key factors in this variation of top speed.

Table 1: Selected AEB Pedestrian systems

No.	OEM	Segment	Model	Variant	AEB Pedestrian System Name
1	Hyundai	C-segment	Elantra (USA 2021)	Smartstream G1.6 Premium	Forward Collision-Avoidance Assist (FCA) System (Hyundai, 2021)
2	Hyundai	C-segment	i30N	Performance (Manual)	Forward Collision-Avoidance Assist (FCA) System (Hyundai, 2021)
3	Hyundai	B-segment	Kona (2021)	Smartstream G1.6 T-GDI	Forward Collision-Avoidance Assist (FCA) System (Hyundai, 2021)
4	Nissan	D-segment	Altima (USA 2020)	S	Automatic Emergency Braking (AEB) with Pedestrian Detection (Nissan, 2021)
5	Nissan	B segment	Leaf (USA 2019)	110kW AC Synchronous Electric Motor	Intelligent Forward Collision Warning with Intelligent Emergency Braking (Nissan, 2021)
6	Nissan	SUV C	X-Trail	2.5 4WD	Intelligent Forward Collision Warning with Intelligent Emergency Braking (Nissan, 2021)
7	Perodua	A-segment	Bezza	1.3 V	Advance Safety Assist (ASA) 2.0 (Perodua, 2020)
8	Perodua	SUV B	Ativa	AV	Advanced Safety Assist (A.S.A.) 3.0 - Pre-Collision Braking (Perodua, 2021)
9	Proton	SUV B	X50	Flagship	Autonomous Emergency Braking - Pedestrian
10	Toyota	C-segment	Corolla (USA 2020)	1.8 E	Toyota Safety Sense 2.0 Pre-Collision System (PCS) (Toyota, 2020)
11	Toyota	B-segment	Yaris (2021)	1.5 E	Toyota Safety Sense (TSS) with Pre-Collision System (PCS) (Toyota, 2020)
12	Toyota	SUV C	CHR	N/A	Toyota Safety Sense (TSS) with Pre-Collision System (PCS) (Toyota, 2021)
13	Volkswagen	C-segment	Passat (2021)	2.0 Elegance	Anti-lock Braking System (ABS) with Brake Assist (BA) and Electronic Braking Distribution (EBD)
14	Volkswagen	C-Segment	Golf (UK 2020)	Life	Front Assist Anti-lock Brake System (ABS) with Hydraulic Brake Assist (HBA)
15	Volkswagen	SUV C	Tiguan (USA 2016)	2.0 SE 4WD	Pre-Crash Brake system (Front Assist)

For pedestrian speed ranges, all cars show a similar pedestrian working speed range from 4 km/h to a maximum speed range of 60 km/h to 85 km/h. This pedestrian speed range represents the majority speed range of VRU can have, for pedestrians or cyclists. Most of the working range is activated at 10 km/h to (60-80) km/h which is based on higher chances for the avoidance of any form of pedestrian/cyclist collision assisted by the system. According to Rizzi et al. (2014), a lower speed detection range provided a higher chance of total avoidance of this unforeseen collision with fragile human beings.

3.0 DETECTION SYSTEM

A detection system is a crucial aspect of the functionality of AEB Pedestrian where it triggers the onset of the collision intervention process. Successful collision intervention depends on the system's capability to detect the object accurately and at the earliest as possible (Doecke et al., 2012). As detection sensors are located in the frontal section of the car, AEB only serves to prevent the forward collision. AEB system will detect, receive, process, and respond to system triggers with mechanical actuation for the braking process, together with visual or audio warnings. Figure 1 shows examples of visual warning displays, which are part of the AEB system.

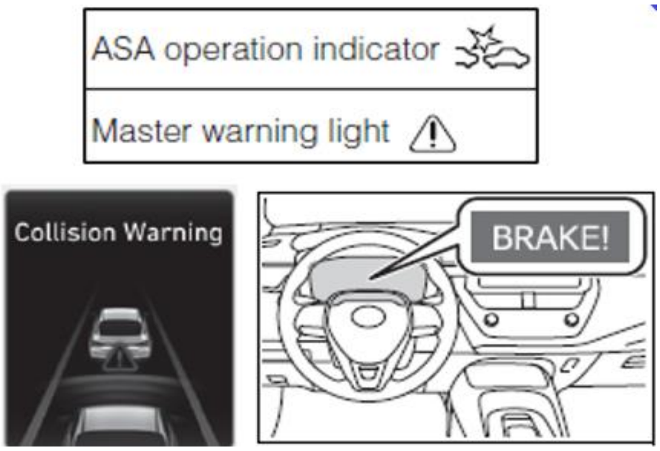

Figure 1: Two different visual warning displays; one being symbol dependent (top) and the other one being wording expression (bottom) (Perodua, 2020; Nissan, 2021)

The detection mechanism can be one or more devices. A.S.A 2.0 utilized only a camera as its detection device while many of its competitors utilized both camera-radar sensors. A work by Schram et al. (2013) shows that the angle of the radar system with respect to different positions of the vehicle is the main specification that needs to be improved for future detection enhancement.

The camera location is mostly located at the top center of the windshield pointing forward of the vehicle and the radar sensor can be either at the backside of the front vehicle emblem (Toyota, Nissan, Volkswagen) or the bottom front grille near the vehicle registration plate (Hyundai). Generally, most AEBs used a single mono camera and 77 GHz millimeter wave radar capable of 150 m to 170 m detection. Only A.S.A 2.0 utilized a stereo camera as its sole detection device.

Proton Autonomous Emergency Braking Pedestrian, Toyota Safety Sense (TSS), Nissan AEB with Pedestrian Detection, Volkswagen Front Assist with ABS and Hydraulic Brake Assist (HBA), Hyundai FCA, and Perodua A.S.A. 2.0 has identical AEB operational sequences where during audiovisual warning in alert mode if the driver did not respond immediately, the system exerts pressure on the braking sequence partially. If the driver is still not in alertness mode over the sudden circumstances, it can either progress into the next phase of safety assistance for collision mitigation such as steering intervention or continue to apply more braking pressure. The AEB response will be deactivated after the vehicle stop for at least two seconds, thus allowing the driver to safely take control of the situation.

4.0 LIMITATION OF AEB

For a fully functional AEB system, the detection mechanism device must prevent any form of unfavorable conditions. Examples of these conditions include exposure to high temperature for a long period, accumulation of dirt and dust particles, cracked windshield, exposure to high pressured-water jet (as in car wash), and others. Issues surrounding ABS (Anti-lock Braking System) such as tire condition, brake disc and/or pad condition, suspension modification over authentic parts, cargo area overload resulting in inclination of the car stability, and AEB faulty indicator can be a hindrance to the functionality of AEB.

Climate conditions – such as thunderstorms, heavy rain, and foggy vision – affected the detection mechanism (from all car manufacturer owner's manuals). The level of brightness and shadiness give different readings on the detection system such as sudden entrance into dark areas, such as tunnels or rural areas with improper road lighting conditions. Unstable terrain and road condition with obstacles such as mud and potholes can have dirt covering the headlamps, thus reducing light reference for the camera and radar sensor to function.

Detection of pedestrian movement also poses challenges. The unpredictable movement of pedestrians and cyclists with limited details of information interpretation over the moving limbs, appearance, and human anatomy in general, can be disadvantages for detection mechanisms.

The irregular shape of the detected object can cause misinformation to the AEB detection system. In circular motion such as roundabout and sudden inclination or declination due to uphill and downhill road conditions can make the object facing the camera or radar as halved or part of the full image. Figure 2 shows an object standing in the way of the camera within the interior side resting on the dashboard area can also affect the AEB detection system. Large scale vehicles such as buses, lorries, and irregularities in standard vehicles such as spoiler modification or dented rear-end area of a vehicle can also pose difficulty in successful object detection.

In short, the limitation of the AEB system can be categorized into four aspects: detection equipment functionality and its maintenance, vehicle conditions, climate conditions, and road conditions. Certain AEB systems have already been enhanced with image processing based on Artificial Intelligence (AI) is certainly the near-future solution for the current limitation.

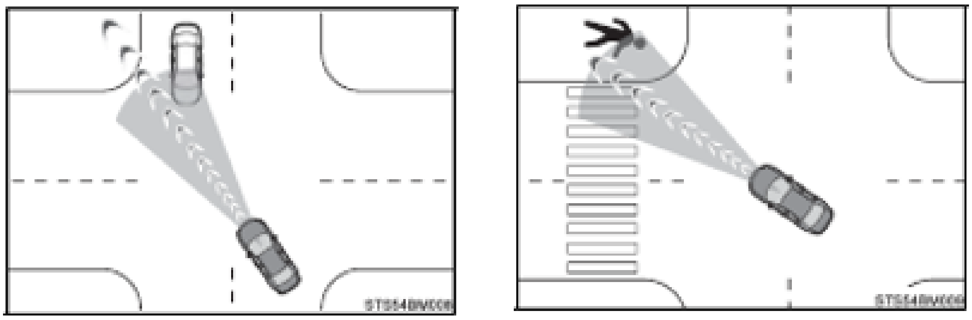

Figure 2: High probability of inactivation of AEB: Intersection zone where line of sight from the frontal side of the vehicle (left) and pedestrian (right) is limited (Perodua, 2021)

5.0 SPECIAL FEATURES OF AEB SYSTEM

Safety features here are termed as other technology or added safety support that can be actuated prior to or in the aftermath of the AEB system process. Total collision avoidance within the acceptable speed limit of the vehicle can be achieved with those auxiliary systems that either can function as singular independent systems or enhanced secondary systems coming from AEB sequential operation. Emergency Steering Support (ESS) as stated by Euro NCAP, is an example of implementing such logical avoidance feedback from the AEB system, where it must be initiated manually by the driver (Schram, 2019). ESS falls under the categorization of independent systems and functionality comes after AEB sequences are activated with spontaneous reflex from the driver in steer handling during the avoidance of unpredictable situations. Toyota Safety Sense, offer this combined system within its Advance Driver Assistant System (ADAS) system which includes the AEB system and ESS system known as Toyota Emergency Steering Assist. Toyota ESS system is activated based on a pre-programmed prediction of the possibility for the vehicle to collide with pedestrians and calculate sufficient space for steering within the vehicle's current lane. This additional feature aids the sudden steering movement into better handling with optimized vehicle stability and lane departure prevention.

Another additional safety support for AEB is known as Lane Departure Assistance (LDA) which is incorporated within the ESS system in terms of its operational method. It prevents the vehicle take an extreme diversion from the spontaneous steering response, prompting another dedicated visual and audio warning for the driver. As an independent system, the LDA function can be categorized into three forms of safety execution: lane-keeping assist, lane departure warning, and lane departure prevention. There are five processes in the execution of LDA: data acquisition, region of interest (RoI) segmentation, lane detection, vehicle positioning tracking, and Alert notification (Chee & Lau, 2017).

These special features offered by car manufacturers serve as an added value to their ADAS system and add to system marketing value. For example, the latest model from Perodua, Ativa equipped with their enhanced ADAS, A.S.A. 2.0 where lane departure warning, lane departure prevention, and lane keep control are available in any standard car model. Figure 3 describes pictures showing the difference between all these features in A.S.A. 2.0.

Hyundai Blind-spot Collision Warning (BCW) and Blind-spot Collision-Avoidance Assist (BCA) are other add-on technologies to the AEB Pedestrian system. It can be useful in some situations such as, for the vehicle in a position to execute reverse parking. Nissan

Intelligent Driver Alertness (I-DA) gives another example of a special feature of the AEB system. I-DA is programmed to record the driver's daily driving pattern in terms of steering control and driving style. If there is a slight difference in the driving condition, predictive feedback will prompt an audiovisual warning to the driver.

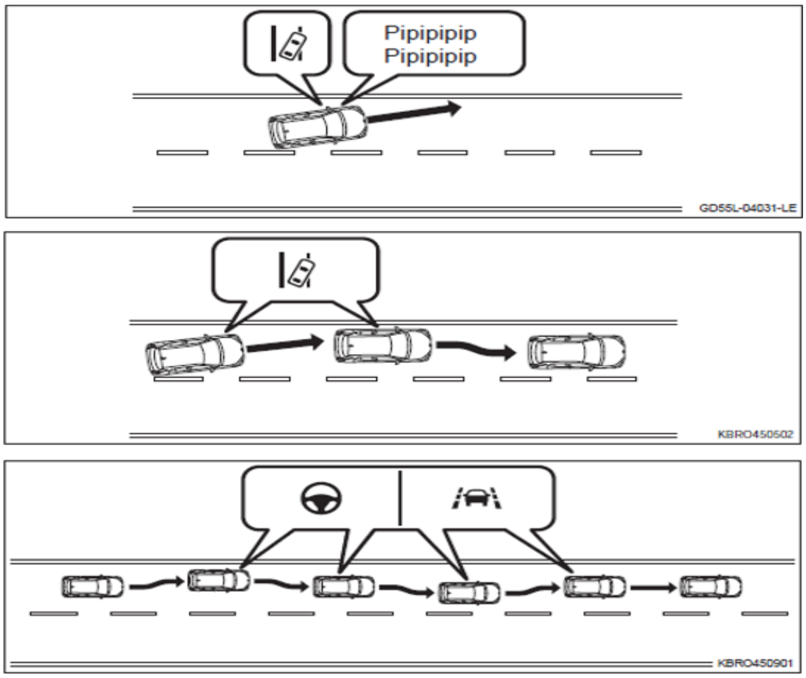

Figure 3: Lane Departure Warning (top), Lane Departure Prevention (middle), and Lane Keep Control (bottom) additional features aid in the AEB pedestrian system for Perodua A.S.A. (Perodua, 2021)

6.0 AREAS OF IMPROVEMENT

In the next years, as AEB pedestrian systems will be more prevalent for cars due to high demand and through pressure from regulations, researchers must improve the system in several areas. One of them is the decision-making process of the AEB system in which Artificial intelligence can play an important role. As human and animal road crossings can present complex cases, whereby the geometry of objects and scenarios can be intriguing, Artificial Intelligence (AI), specifically Machine Learning technique, is equipped to circumvent the issue. However, work still needs to be done, as countless different shapes of objects, scenarios, and surrounding issues persist. Some examples of research work applying artificial intelligence to improving AEB systems can be found in the works of Chae et al. (2017), Dubey et al. (2020), and Schachner et al. (2020). Current technology of using image processing technique has some flaws in detecting imperfect shapes due to different object configurations or due to external factors, such as weather.

The Effectiveness of the AEB pedestrian system at high speed still needs to be developed further. The current AEB pedestrian systems have working speeds, ranging from 4 km/h to 80 km/h established among all car manufacturers with an exceptional speed of 120 km/h claimed by the latest model from Perodua which is Ativa representing the SUV B segment. Improvement on the detection mechanism with the incorporation of deep learning capability can enhance the decision-making process, making the triggering of AEB pedestrian starts earlier by adapting dynamic time-to-collision (TTC) to the road condition, different payloads, and tire pressure (Xia et al., 2013). This enhancement can make the AEB pedestrian system function at a higher working speed range.

Another area that needs to be looked at is the issue of a wide variety of road conditions that can hamper the AEB system. For example, braking downhill needs earlier triggering while going uphill needs later triggering. Using Machine Learning techniques such as reinforced learning or deep reinforced learning can further improve the adaptability of the AEB system to different road conditions.

7.0 CONCLUSION

In general, the majority of car manufacturers employ an AEB Pedestrian system with a similar working speed range, (4 km/h to 80 km/h), the same pedestrian speed range (4 km/h to 60 km/h - 85 km/h), and same detection mechanism: radar and camera. All of them have the same major limitation which is on their non-robust image processing tool to detect adjacent VRU, which the detection is prone to external interference by irregular road conditions, weather, dirt, mud, and other obstruction. Future improvement of AEB lies in the advancement of Machine learning techniques where several datasets can be utilized to better detect VRU of any conditions.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the assistance and guidance given by the Malaysian Institute of Road Safety Research (MIROS) and the ASEAN NCAP secretariat through the ASEAN NCAP Collaborative Holistic Research (ANCHOR) program (Grant No. A3-C231).

REFERENCES

Anderson, R., Doecke, S., Mackenzie, J., & Ponte, G. (2013). Potential benefits of Autonomous Emergency Braking based on in-depth crash reconstruction and simulation. In Proceedings of the 23rd International Conference on Enhanced Safety of Vehicles, US National Highway Traffic Safety Administration, Washington DC.

Ariffin, A. H., Jawi, Z. M., Isa, M. M., Kassim, K. A., & Wong, S. (2010). Pedestrian casualties in road accidents – Malaysia perspective. In Proceedings of MIROS Road Safety Conference (pp. 280-289).

Baharuddin, M. I., Khamis, N. K., Kassim, K. A., & Mansor, M. R. A. (2019). Autonomous Emergency Brake (AEB) for pedestrian for ASEAN NCAP safety rating consideration: A review. Journal of the Society of Automotive Engineers Malaysia, 3(1), 63-73.

Chae, H., Kang, C. M., Kim, B., Kim, J., Chung, C. C., & Choi, J. W. (2017). Autonomous braking system via deep reinforcement learning. In 2017 IEEE 20th International conference on intelligent transportation systems (ITSC) (pp. 1-6). IEEE.

Chee, W., & Lau, P. Y. (2017). A framework for Lane Departure Warning System for various lane markings. In 2017 Proc. of International Workshop on Advanced Image Technology (IWAIT 2017).

Chong, S. L., Chiang, L. W., Allen Jr, J. C., Fleegler, E. W., & Lee, L. K. (2018). Epidemiology of pedestrian–motor vehicle fatalities and injuries, 2006–2015. American Journal of Preventive Medicine, 55(1), 98-105.

Doecke, S., Anderson, R., Mackenzie, J., & Ponte, G. (2012). The potential of Autonomous Emergency Braking systems to mitigate passenger vehicle crashes. in 2012 Australasian Road Safety Research, Policing and Education Conf. (ARSRPE), Wellington, New Zealand.

Dubey, V. S., Kasad, R., & Agrawal, K. (2020). Autonomous braking and throttle system: A deep reinforcement learning approach for naturalistic driving. Proceedings of the 13th International Conference on Agents and Artificial Intelligence (ICAART 2021) – Vol. 1, 173-180.

Eid, H. O., & Abu-Zidan, F. M. (2015). Pedestrian injuries-related deaths: A global evaluation. World Journal of Surgery, 39(3), 776-781.

Hulshof, W., Knight, I., Edwards, A., Avery, M., & Grover, C. (2013). Autonomous Emergency Braking test results. In Proc. of the 23rd International Technical Conference on the Enhanced Safety of Vehicles (ESV) (pp. 1-13). NHTSA, Washington DC.

Hyundai 2021 Elantra Owner's Manual. (2021). Retrieved October 8, 2021, from https://cdn.dealereprocess.org/cdn/servicemanuals/hyundai/2021-elantra.pdf

Hyundai 2021 Kona Owner's Manual. (2021). Retrieved October 8, 2021, from https://cdn.dealereprocess.org/cdn/servicemanuals/hyundai/2021-kona.pdf

Jantan, I. D., Ghani, Y., Makhtar, A. K., Isa, M. H. M., & Jawi, Z. M. (2020). A study on animal and vehicle collisions in Malaysia based on news analysis. International Journal of Road Safety, 1(2), 63-69.

Nissan Altima Sedan Owner's Manual and Maintenance Information. (2021). Retrieved October 20, 2021, from https://www.nissanusa.com/content/dam/Nissan/us/manuals-and-guides/altima/2021/2021-nissan-altima-owner-manual.pdf

Nissan 2019 LEAF Owner's Manual. (2019). Retrieved October 8, 2021, from https://owners.nissanusa.com/content/techpub/ManualsAndGuides/LEAF/2019/2019-LEAF-owner-manual.pdf

Perodua Bezza Owner's Manual. (2020). Retrieved October 8, 2021, from https://eownersmanual.perodua.com.my/assets/pdf/1620199176523_ombezza2020.pdf

Perodua Ativa Owner's Manual. (2021). Retrieved October 8, 2021, from https://eownersmanual.perodua.com.my/assets/pdf/1626684048144_omativaen2021.pdf

Rizzi, M., Kullgren, A., & Tingvall, C. (2014). Injury crash reduction of low-speed Autonomous Emergency Braking (AEB) on passenger cars. In Proc. of IRCOBI Conference on Biomechanics of Impacts.

Saadé, J. (2017). Autonomous Emergency Braking, AEB (pedestrians & cyclists). European Road Safety Decision Support System, developed by the H2020 project SafetyCube. Retrieved from www.roadsafety-dss.eu

Said, M. M., Mohd, M. S., Faye, I., Husain, N. A., Kamaruddin, T. T., & Dol, S. S. (2021). Review of current Animal-Vehicle Collision (AVC) studies. Journal of the Society of Automotive Engineers Malaysia, 5(1), 64-71.

Schachner, M., Sinz, W., Thomson, R., & Klug, C. (2020). Development and evaluation of potential accident scenarios involving pedestrians and AEB-equipped vehicles to demonstrate the efficiency of an enhanced open-source simulation framework. Accident Analysis & Prevention, 148, 105831.

Schram, R., Williams, A., & van Ratingen, M. (2013). Implementation of Autonomous Emergency Braking (AEB), the next step in Euro NCAP's safety assessment. In 23rd Intern. Technical Conf. on the Enhanced Safety of Vehicles (ESV), Seoul, Republic of Korea,

Schram, R. (2019). Euro NCAP's first step towards scenario-based assessment by combining Autonomous Emergency Braking and Autonomous Emergency Steering. In 26th International Technical Conference on the Enhanced Safety of Vehicles (ESV): Technology: Enabling a Safer Tomorrow, National Highway Traffic Safety Administration (No. 19-0182).

Toyota 2020 Corolla Owner's Manual (2020). Retrieved October 8, 2021, from https://www.toyota.com/t3Portal/document/om-s/OM02580U/pdf/OM02580U.pdf

Toyota 2021 C-HR Owner's Manual (2020). Retrieved October 8, 2021, from https://www.toyota.com/t3Portal/document/om-s/OM10684U/pdf/OM10684U.pdf

Verzosa, N., & Miles, R. (2016). Severity of road crashes involving pedestrians in Metro Manila, Philippines. Accident Analysis & Prevention, 94, 216-226.

WHO (2018). Global status report on road safety. World Health Organization, Geneva. Retrieved from https://www.who.int

Xia, L., Tran, D. C., & Abu Kassim, K. A. (2013). A review of Automated Emergency Braking System and the trending for future vehicles. Proceedings of the Southeast Asia Safer Mobility Symposium 2013, Melaka, Malaysia.